CICOR
Cooperative Institute for Climate and Ocean Research
Dr. Robert A. Weller, CICOR Director

Annual Progress Report
July 1, 2002 - June 30, 2003

submitted to

National Oceanic and Atmospheric Administration
Ocean and Atmospheric Research (OAR)

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CICOR

(Cooperative Institute for Climate and Ocean Research)

CICOR is a Cooperative Institute between National Oceanic and Atmospheric Administration (NOAA) and the Woods Hole Oceanographic Institution (WHOI).

The research activities of CICOR are organized around three themes:

the coastal ocean and near shore processes,
the ocean's participation in climate and climate variability and
marine ecosystem processes analysis.

These theme areas, each of which has significant implications for human society, are interrelated and scientific progress will require collaborations by scientists within and between disciplines. In each case, progress will depend on a combination of fundamental process studies, the development and deployment of technological systems for sustained observation, and the development of predictive models that are based on an understanding of the underlying processes and that assimilate information from the observational systems.

CICOR has been in existence for five years. During the first 3-year Cooperative Agreement it assisted WHOI Scientists with 26 funded projects totaling a budget of $5,817,000. For the first two years of this next 5-year Cooperative Agreement, 27 projects were funded with a total budget of $7,375,000. The program development fees covered four post-docs and two graduate students, along with short term visitors, whose work fell under the three CICOR Themes, Ocean’s Participation in Climate, Coastal Oceanography and Near-Shore Processes and Marine Ecosystem Processes.

For more information
http://www.whoi.edu/science/cicor

CICOR Task I Accomplishments for July 1, 2002 – June 30, 2003

The Cooperative Institute for Climate and Ocean Research (CICOR) began the second year of the five-year NOAA-WHOI CICOR Cooperative Agreement. This is the second annual summary report document covering the time period July 1, 2002 through June 30, 2003.

CICOR Activities supported by Task I funds include:

Jul 2002	Second year of Agreement begins - 20 proposals funded Amy Baco-Taylor 4th CICOR Postdoc arrives Jim Lerczak, 18 month CICOR Postdoc, accepts WHOI staff position
Sept 2002	Final Summaries for 1st 3-year plus extension Cooperative Agreement prepared for NOAA/OAR JI Director's Meeting at CIRES, CO 9/25-27
Oct 2002	Annual Summaries of year 1 of 5-year Agreement submitted to NOAA
Nov 2002	Hot Item on NOAA web page PI Dana Yoerger, AOP&E Dept. "Great Success and High Expectations – Submarine Ring of Fire"
Feb 2003	5th Blue Lobster Bowl – National Ocean Science Bowl
Mar 2003	Falmouth High School Science Fair – CICOR Marine Sciences Award Ruoying He 5th Post-Doc accepts position
Apr 2003	Hot Item on NOAA web Don Anderson, Biology Dept. "ECOHAB and GLOBEC Workshop"
Jun 2003	27 Proposal Awards for the 2 years of the 5-year Cooperative Agreement New Item on Web SCIENCE ONLINE

Personnel for CICOR Annual Summary Report July 1, 2002 – June 30, 2003

Task I Support

Employees	**Appt. Dates**
Bob Weller, CICOR Director	1999-2003

Task I and Development Costs Support Post-Docs and Joint Program Students

Post-Doc	**CICOR Theme**	**Appt. Dates**	**Advisor(s)**
Ryuoing He	Coastal/Climate	2003-2005	Dennis McGillicuddy Bob Beardsley
Amy Baco-Taylor	Marine Ecosystem Proc.	2002-2003	Tim Shank
Livui Giosan	Climate/Coastal	2001-2003	Lloyd Keigwin
Jim Lerczak	Coastal/Near-Surface Proc.	2000-2002	Dave Chapman, Carin Ashjian
Fiamma Straneo	Climate/Climate Variability	1999-2002	Bob Pickard

Graduate Student	**CICOR Theme**	**Appt. Dates**	**Advisor(s), Dept.**
Rob Jennings	Marine Ecosystems	2000-	Lauren Mullineaux
Steve Fries	Coastal/Near-Surface Proc.	2000-2001	Jim Ledwell

Activity Summary for Liviu Giosan
CICOR Post-Doc 2001 - 2003

In September 2001, Liviu Giosan arrived on a CICOR Postdoctoral Scholarship at WHOI from State University of New York at Stony Brook where he completed his Ph.D. Since then, Liviu has continued his work on sediments from the Blake Ridge sediment drift drilled during ODP Leg 172 for recovering climatic information over the Pliocene-Pleistocene. Four scientific papers resulting on this subject will be published in Marine Geology in 2002 (see references below). Reflectance spectra collected during Leg 172 were used in concert with solid phase iron chemistry, carbonate content, and organic carbon content measurements by Giosan et al. (2002a) to evaluate the agents responsible for setting the color in sediments. Factor analysis has proved a valuable and rapid technique to detect the local and regional primary factors that influence sediment color. On the western North Atlantic drifts, sediment color is the result of primary mineralogy as well as diagenetic changes. Sediment lightness is controlled by the carbonate content while the hue is primarily due to the presence of hematite and Fe^{2+}/Fe^{3+} changes in clay minerals. Hematite, most likely derived from the Permo-Carboniferous red beds of the Canadian Maritimes, is differentially preserved at various sites due to differences in reductive diagenesis and dilution by other sedimentary components. Various intensities for diagenesis result from changes in organic carbon content, sedimentation rates, and H_2S production via anaerobic methane oxidation. Iron monosulfides occur extensively at all high sedimentation sites especially in glacial periods suggesting increased high terrigenous flux and/or increased reactive iron flux in glacials. Further, carbonate content estimated by Giosan et al. (2001) from reflectance spectra at the Leg 172 sites were used by Grützner, Giosan et al. (2002) to develop age models covering the past 0.8-0.9 Ma, by tuning variations of estimated carbonate content to the orbital parameters precession and obliquity. Using these age models, color variations at the Leg 172 sites were interpreted in paleoceanographic terms by Giosan et al. (2002) for the late Pliocene - Pleistocene. In the last 800 kyr sedimentation pattern changes on the Blake-Bahama Outer Ridge were determined by the sediment delivery to the deep basin as well as circulation changes. Sediment delivery increased during glacials (especially during the last 500 kyr and particularly since Stage 6). A fundamental change in the thermohaline circulation occurred at about ~500 ka corresponding to the end of the Mid-Pleistocene Transition period at the onset of the predominant 100-kyr climate cyclicity. Sedimentation related to WBUC had intensified at that time and had become more focused at depths below 3000 m. Abundance of Upper Carboniferous spores indicates that the hematite is probably derived from the Permo-Carboniferous red beds of the Canadian Maritimes. Changes in hematite content and sedimentation rate show a pulse of sediment via the St. Lawrence outlet at the Pliocene-Pleistocene boundary suggesting that a likely change in the hydrography and/or physiography of the Laurentide Ice Sheet could have been involved in the climatic and ocean circulation changes at that time.

The migration history of an abyssal mud wave on the Blake-Bahama Outer Ridge (ODP Site 1062) has been studied by Flood and Giosan (2002) through the analysis of multiple ODP holes spaced across the mud wave. Additional information about wave migration patterns comes from 3.5 kHz records and seismic profiles. These data suggest that mud wave migration has varied during the last approximately 10 Ma. Seismic profiles suggest wave migration was initiated about 8 to 10 Ma, and wave migration was pronounced from about 5 Ma to about 1 Ma (with an episode of strong flow about 4.5 Ma). Analysis of sediment cores suggests that migration rates have been somewhat lower and have varied during the last 1 Ma. Intervals of no wave migration are observed for several time intervals and appear to characterize deglaciations, especially during the last 500 kyrs. Comparisons between seismic profiles and the core record show that most of the seismic horizons correlate closely with time horizons, and thus that the seismic profiles give a reasonable representation of mud wave migration. Models suggest that wave migration is more pronounced during periods of higher bottom current flow and less pronounced during periods of lower current flow. Thus the migration record is consistent with generally higher bottom flow speeds at this site prior to 1 Ma and lower bottom flow speeds after 1 Ma. The transition from a dominant climatic period at 40 kyrs to a dominant climatic period at 100 kyrs occurs at about this time, suggesting an overall reduction in bottom flow speed at this site coincident with changing climate patterns. These changes in flow speed could be related to changes in the depth of the flow as well as to changes in the speed of thermohaline circulation.

In April-May 2002, Liviu Giosan participated in the ODP Leg 202 drilling in southeast Pacific. During the cruise, he employed analysis of reflectance spectra and other physical properties to detect climatic changes recorded by the drilled sediments. One interesting result of this preliminary research, has been the detection of a link between the uplift of the Andes and eolian activity and ocean circulation in the southeast Pacific.

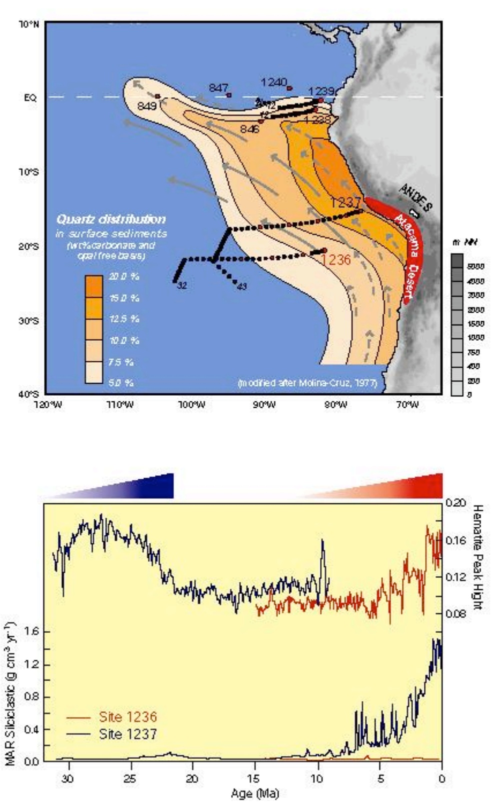

Figure. Wind directions and the extension of the SE Pacific dust plume originating in Peru-Chile deserts (after Molina-Cruz, 1977). The present positions and tectonic backtracks for sites drilled by Leg 202 that are potential recipients of a South American dust plume are shown together with a preliminary reconstruction of the aridity/wind activity based on estimated hematite contents and mass accumulation rates of siliciclastic sediments at sites 1326 and 1237. (*Figure to be printed in Leg 202 Initial Reports*)

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Today, the Andean barrier leads to enhanced precipitation from the trade winds on the eastern side of the mountain chain. Heavy rainfalls form a major source for the Amazon River, which drains its sediment load into the Atlantic. The western side suffers from a rain shadow rainshadow effect and drier climate conditions, in the Atacama desert. The long-term history of eolian deposition in the subtropical southeastern Pacific is probably best recorded at Sites 1236 and 1237 drilled during Leg 202 (see figure above). Today, both sites underlie the path of eolian transport from the Atacama Desert in Chile. The southeast trade winds are the major dust carrier carriers as indicated by the pattern of quartz distribution in southeast Pacific surface sediments (Molina-Cruz, 1977). The presence of terrigenous hematite and goethite goethite, as well as other mainly clay-sized siliciclastics at Sites 1236 and 1237 (see figure), is indicative of a far-field eolian component. The combined records of these tracers suggest that eolian dust has accumulated in the subtropical southeast Pacific since at least the late Oligocene. The hematite record, reconstructed from reflectance data, suggest an increased aridity on South America during Oligocene, prior to the uplift of the Andes. Aridity in this region could have been the result of loss of humidity by the southeast trade winds along their continental path across South America and the presence of the adjacent cool Peru-Chile Current. Since the late Miocene and Pliocene, eolian iron oxides, complemented by a significant eolian siliciclastic fraction, indicate steplike increases in eolian deposition, that are paralleled by an increase in coastal upwelling and productivity. A change in atmospheric circulation could explain both features. Intensified trade winds would enhance equatorial upwelling/productivity and the northward advection of nutrient-rich waters transported by the Peru-Chile Current. Modern upwelling along the Peruvian continental margin occurs over a broader region than just a very narrow coastal strip, due to topographic steering by the newly uplifted Andes. Liviu will test these hypotheses by evaluating the validity of using iron oxides as eolian proxies and by reconstructing the wind history. Liviu will also work in cooperation with Konrad Hughen at WHOI on a detailed sedimentary sequence recovered during Leg 202 on the Chilean slope. The objective is to reconstruct links between the South American climate and ocean circulation in the southeast Pacific using ultra-high resolution records of continental vegetation, riverine efflux, and sea surface temperature. Funding for these preliminary studies will be provided to Giosan from USSSP/NSF.

Liviu continued his collaborative studies on wave-influenced deltas and presented his work at the 2001 GSA's annual meeting in Boston and at a USGS-sponsored talk at WHOI in the fall of the same year. A paper on this subject is in revision for *Sedimentology* and another paper is in preparation for submission to *Geomorphology*. He is preparing proposals for initiating field work in the Danube and Indus deltas. In cooperation with Janok Bhattacharya, Liviu has organized a session on deltas that he will co-chair at the GSA Annual Meeting in Denver in October 2002. Given the high quality of the works to be presented at the session, a special volume of the Society for Sedimentary Geology (SEPM) is now edited by Giosan and Bhattacharya. A paper titled "Large scale coastal behavior in delta: A Danube delta overview" with Liviu Giosan as the first author is in preparation for that volume. Liviu together with Jeff Donnelly have been awarded a Coastal Institute grant for studying the Danube delta: field work will begin in Fall 2003. Also Peter Clift and Liviu Giosan have been recently funded by NSF to study the Indus delta.

Liviu's previous work in the Black Sea area has resulted in a collaborative proposal submitted to NSF together with Bill Ryan from Lamont-Doherty Earth Observatory to test that in glacial and deglacial times these seas acted as Eurasian analogues to the giant amplifier lakes of the USA's Great Basin. Strontium, oxygen and carbon isotopes on both mollusc shells and precipitated calcite in association with indicators of ancient shoreline positions, depositional environments and sediment provenance will be used to explore the possibility that the Black and Marmara Seas, like the landlocked Caspian, expanded during cold periods and shrank during warm periods when global sea level lay below their inlets. Modern humans migrated into Anatolia and Eurasia during these climate shifts. Key cultural milestones, such as the origin of farming and the rapid maritime colonization of the western Mediterranean coincide with abrupt changes in temperature and precipitation, but surprisingly such events occurred during cold periods and are inadequately explained. The insight gained from this proposed study into the last 25 ky BP should also help pave the way to future IODP drilling by strengthening the palaeoceanography-palaeoclimate component. Related to this latest subject, Liviu together with Roger Flood (SUNY Stony Brook) have been awarded funding for organizing a mini-workshop on drilling in the Black Sea. The workshop will take place in Stony Brook in October, 2003. In the meantime, a paper with Liviu as a co-author on "Testing the physical oceanographic implications of the suggested sudden Black Sea in-fill 8400 years ago" is in press in the journal Paleoceanography.

Closer to WHOI, Liviu Giosan and one of his mentors at WHOI, Lloyd Keigwin, have been awarded a 2002 Ocean and Climate Change Institute (OCCI) Research Award. A major physical oceanography initiative at WHOI aims to collect a new dataset on the deep western boundary current (DWBC) interannual circulation in the North Atlantic via moored and hydrographic-velocity-tracer observations on a transect that will extend from the New England shelf to Bermuda. The DWBC is a major branch of the thermohaline circulation and an important component of the global heat balance. A cruise that will service Station W in the fall of 2002 will be added one additional day using the OCCI award for acoustically surveying (3.5 kHz) and coring on two transects off Martha's Vineyard and Nantucket. The main goal of this work is to identify subsurface sedimentary features indicative of good paleoclimatic records that could be recovered by coring. If suitable sedimentary records can be recovered on the New England slope, the higher understanding of the DWBC regime that will come from the modern study performed by the physical oceanography team can be used to enhance understanding of the paleocirculation at a key, easily accessible location on the path of WHOI ships' cruises. Keigwin and Giosan will apply a similar approach for the Colombian margin of the Panama Basin for which they have been recently funded by the Earth System History program at NSF.

Liviu Giosan has been also involved in more synergistic activities. He participated at a workshop on the transport, transformation, and fate of carbon in river-dominated ocean margins (RIOMAR) and another workshop dedicated to the future participation of US scientific community at the new Integrated Ocean Drilling program. Liviu also has founded and led a new Internet-based journal dedicated to the young Romanian scientists (see www.ad-astra.ro).

References

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Giosan, L., Flood, R.D., Aller, R., 2002a. Paleoceanographic significance of sediment color on western North Atlantic drifts: I. Origin of color. Mar. Geol.

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Flood, R.D., Giosan, L., 2002. Migration History of an Abyssal Mud Wave on the Bahama Outer Ridge. Mar. Geol.

Bhattacharya J. and Giosan, L., in revision. Geomorphology of wave influenced deltas: Implications for facies interpretation, Sedimentology,

Giosan, L., Vespremeanu, E., Buonaiuto, F., in preparation. Wave-influenced asymmetrical deltas: The typical example of Danube's St. George Lobe

Activity Summary for Amy R. Baco-Taylor
CICOR Post-Doc 2002-2003

I arrived at WHOI in June of 2002. Since then I have submitted two papers from my dissertation, one is published and the other is currently in press. In the lab, I am focusing on one research project, examining the population genetics and dispersal of deep-sea precious corals from the Hawaiian Archipelago. These corals are the focus of a profitable fishery, yet little is known about their dispersal capabilities or general ecology. I am using microsatellite methods to address these issues. The findings of this research will help improve the management of these species as well as improve our general understanding of dispersal in the deep-sea. Most of my time has been spent learning new microsatellite methods and developing useable microsatellite markers for my study. So far I have obtained 7 microsatellite loci for one of these species. I am preparing a manuscript from this research and have presented the results at three international conferences.

I have also submitted several proposals related to the ecology and evolution of seamount fauna. Two of these proposals have been funded, both through NOAA's Office of Ocean Exploration. I will have a cruise in Sept- Nov. 2003 to the Northwest Hawaiian Islands to document the distribution of deep-sea corals on 3 previously unexplored seamounts. I will also collect deep-sea corals from 4-5 additional sites in the Northwestern Hawaiian Islands to add to my current study of dispersal and population genetics of Hawaiian deep-sea precious corals.

A third proposal is currently pending with NOAA NURP Alaska. I participated in an Ocean Exploration cruise to the Gulf of Alaska Seamounts where I collected deep-sea corals and other seamount invertebrates. Based on observations from this cruise I submitted a proposal (to NOAA-NURP Alaska) to return to the same seamount chain to further examine their fauna and to use molecular methods to determine levels of dispersal in some of the dominant taxa.

Submitted Publications:

Baco, A.R. and C.R. Smith. In Press. High biodiversity levels on a deep-sea whale skeleton. *Marine Ecology Progress Series*.

Baco, A.R. and T.M. Shank. Population Genetic Structure of the Hawaiian Precious Coral *Corallium lauuense* Using Microsatellites. In prep for special volume *Hydrobiologia*.

Smith C.R. and A.R. Baco. 2003. Ecology of whale falls at the deep-sea floor. *Oceanography and Marine Biology Annual Review* 41: 311-354.

Summary Report July 1, 2002 to June 30, 2003
CICOR Joint Program Student Rob Jennings, Biology Dept.
Advisor Lauren Mullineaux

I have spent most of the past year investigating population genetic variation of the marine polychaete worm *Clymenella torquata* (a bamboo worm of the family Maldanidae). During the summer of 2002, I collected ~30 worms from each of several sites around Cape Cod (Buzzards Bay, Hyannisport, Stage Harbor, Pleasant Bay, and Barnstable Harbor), as well as from Pembroke, ME and Belmar, NJ. I sampled these sites again in the summer of 2003, and added samples from Chance Harbor, New Brunswick (Bay of Fundy) and Gloucester Point, VA. These worms comprise the study organisms for the first chapter of my dissertation, which consists of a gene flow analysis to determine 1) if the Cape Cod peninsula is an effective biogeographic or genetic barrier between the Gulf of Maine region and the middle Atlantic coast of the U.S., as has often been hypothesized, 2) whether the Cape Cod Canal allows transfer around this putative barrier, and 3) what the patterns of gene flow are in Cape populations of *C. torquata*. I have sequenced the mitochondrial gene ATP6 (involved in the synthesis of ATP) for approximately 3/4 of the worms collectedam investigating amplified fragment length polymorphism (AFLP) analyses for use as nuclear markers. The data obtained thus far indicate little to no contemporary gene flow (that is, each population bears a distinct genetic signature; see Figure One). There are two main genetic signatures (haplotypes) found in all locations, and rarer closely-related haplotypes specific to each location. The presence of only one genetic signature (haplotype) in New Brunswick and only 3 haplotypes in Maine (2 of them rare) indicate that *C. torquata*'s has recently re-colonized these sites, in contrast to the older populations on the Cape and in New Jersey, where there is considerably more haplotype diversity. This pattern of lower genetic diversity in northern sites is typical of glacially influenced dynamics, where ice sheet advances destroy northern populations, which then slowly return and rebuild genetic diversity during interglacial periods.

In addition to the adult collections described above, I collected juvenile (<3cm) worms from Barnstable Harbor for the second objective of my dissertation. These juveniles should provide a better estimate of *dispersal* (which involves only organism movement between locations, as opposed to *gene flow* which includes survival to adulthood and reproduction in the new location) because most benthic (soft-bottom) invertebrates experience extreme mortality (upwards of 90% in some cases) in the period just after dispersal and settlement. Population genetic studies traditionally sample adults, whose genetic diversity may already have been culled by this post-settlement mortality, thus underestimating the true amount of dispersal that occurred.

My third objective has been to develop a theoretical framework for the issues and complexities introduced by the second objective. No current population genetic models incorporate two-stage (i.e., juvenile and adult) dynamics, nor do they consider the possible effects of severe post-settlement mortality. The third objective thus seeks to interpret any differences seen between the *gene flow* estimate of the first objective (based on adults) and the *dispersal* estimate of the second objective (based on juveniles). To further develop the third objective, I traveled to Berkeley, CA, in May 2003 to visit Montgomery Slatkin. Dr. Slatkin is at the forefront of theoretical population genetics, and I discussed with him in general terms the issues and forces that would be important to such a model, as well as its general form. I am hoping this will lead to a more formal collaboration for this chapter of my dissertation.

In the fall semester of 2002, I was the TA for WHOI's new Invertebrate Biology class. The course was designed as a pilot project; it was taught once a week in seminar style, in hopes that it could eventually be built into the sort of full-scale Invertebrate Biology class that WHOI has offered in the past. Professor Stace Beaulieu and I used my trips around the Cape last summer to collect marine invertebrates for the class. TAing this class was a great opportunity for me to help teach the type of class I had just attended in Friday Harbor. I think the course was a great launching point for what will hopefully become a full-time class; the students enjoyed the class thoroughly but cited lack of adequate class time as a serious drawback.

In November 2002, my previous advisor Ken Halanych left WHOI for a position at Auburn University, AL. I was extremely lucky in that the transition happened very smoothly; since I had already felt that I was in effect co-advised by Lauren Mullineaux for some time, becoming her student officially made perfect sense. Tim Shank offered his lab space and equipment to me to continue my molecular work, and John Stegeman has checked in periodically to see that my needs are being met. In February 2003, I wrote a proposal to CICOR asking for research funds to cover my dissertation in Ken's absence. With Lauren Mullineaux's and Nanc Brink's help, the proposal went through smoothly and CICOR has graciously agreed to provide funding for my dissertation in conjunction with WHOI's Academic Programs Office.

CICOR Outreach
Falmouth High School Science Fair, Falmouth, MA March 7-8, 2003

CICOR Outstanding Project in the Marine Sciences Recipient Marley B. Bice Went on to win First Place in Massachusetts !!

Project Summary: Do the Oxygen Isotopes of Foraminifera Record Temperature?

The objective of this project was to examine how well the temperatures inferred from the oxygen isotope ratios ($\delta^{18}O$) in the skeletons of different species of planktonic foraminifera record the temperature of the water in which the forams grew. Scientists studying future climate change use $\delta^{18}O$ in forams from sea floor sediments to understand past climate change. But the isotopic temperature record and month of bloom of different planktonic species is not well understood.

The study area is in the North Atlantic Ocean, near 40°N, 70°W. The samples were collected in 1981-82 and were stored in buffered solutions. I sieved the solutions and extracted carbonate skeletons of several different species of planktonic foraminifera. $\delta^{18}O$ was measured on a mass spectrometer at Woods Hole Oceanographic Institution. Based on salinity, I estimated the $\delta^{18}O$ value of the water for this area and calculated temperatures using a published equilibrium equation. I compared the resulting temperatures to oceanographic measurements made by others in this area of the Atlantic. The results show that the species *Globigerina ruber* pink and *G. sacculifer* are generally good recorders of sea surface temperature. On the other hand, *G. inflata* records winter surface temperature but then tends to live in deeper, colder water during the summer months. I found that some samples had been poorly buffered while in storage so that the low pH in these samples dissolved forams. This meant that I was not able to reconstruct a full year's temperature cycle. The data I did get show that the foram $\delta^{18}O$ records temperature and that *G. ruber* pink and *G. sacculifer* would be the best to use in reconstructing past sea surface temperatures.

CICOR NOAA Web Outreach

NOAA Home Web Page – "in the Spotlight…"
http://www.noaa.gov

"Where the trade winds meet: air-sea coupling in the inter-tropical convergence zone"
J. Tom Farrer, WHOI Joint Program Student
Bob Weller, Senior Scientist, WHOI/CICOR
July 14, 2003

"Boundary Layer Studies in the Stratus Deck Regions of the Eastern Pacific"
Bob Weller, Senior Scientist, WHOI/CICOR
March 2, 2001

NOAA Internal Web Page - "Hot Items"

"Report on ECOHAB/GLOBEC Workshop"
Donald Anderson, BIO April 7, 2003

"Great Success and High Expectations – Submarine Ring of Fire"
Dana Yoerger, AOPE November 12, 2002

"Observing the Ocean's Past and Present"
Andrey Proshutinsky, PO December 21, 2001

CICOR Visitor

Frank Bradley from CSIRO in Australia visited Bob Weller as a guest investigator in March 2003. He and Weller worked on a paper entitled "The Interface or Air-Sea Flux Component of the TOGA Coupled Ocean-Atmosphere Response Experiment and its Impact on Subsequent Air-Sea Interaction Studies".

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submitted
September 29, 2002
revised and resubmitted
August 15, 2004
This is Contribution Number 10790 from the Woods Hole Oceanographic Institution.

Abstract

The interface or air-sea flux component of the Coupled Ocean-Atmosphere Response Experiment (COARE) of the Tropical Ocean-Global Atmosphere (TOGA) research program and its subsequent impact on studies of air-sea interaction are described. The field work specific to the interface component was planned to improve our understanding of air-sea interaction in the tropics by improving the methodology of flux measurements and by collecting a comprehensive set of observations with coverage of a broad range of time and space scales. The strategies adopted for COARE, particularly the on-site intercomparisons, post-experiment studies of instrument performance, and bulk flux algorithm development, ensured the compilation of very high quality data for the basic near-surface meteorological variables and air-sea fluxes. The success in meeting the goals of improved air-sea heat and freshwater fluxes was verified by closure of the ocean heat and freshwater budgets to within 10 W m-2 and 20% respectively. These results confirm that accurate in-situ observations of air-sea fluxes can be obtained during extensive measurement campaigns, and have established the foundation for current plans for global, long-term oceanic observations of surface meteorology and air-sea fluxes. At the same time, some uncertainties remained after COARE, which must be addressed in future studies of air-sea interaction.

NOAA Progress Report

A Northwest Tropical Atlantic Station for Flux Measurement (NTAS)

NOAA Grant: NA17RJ1223
July 1, 2002 to June 30, 2003

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Program Manager: Michael Johnson, NOAA OGP

Background

The Northwest Tropical Atlantic Station (NTAS) project for air-sea flux measurement was conceived in order to investigate surface forcing and oceanographic response in a region of the tropical Atlantic with strong SST anomalies and the likelihood of significant local air-sea interaction on seasonal to decadal time scales. The strategy is to maintain a meteorological measurement station at approximately 15 N, 51 W through successive (annual) turn-arounds of a surface mooring. Redundant meteorological systems measure the variables necessary to compute air-sea fluxes of heat, moisture and momentum using bulk aerodynamic formulas.

Objectives

NTAS has two primary science objectives. First, to determine the air-sea fluxes of heat, moisture and momentum in the northwest tropical Atlantic using high-quality, in-situ meteorological measurements from a moored buoy. Second, to compare the in-situ fluxes to those available from operational models and satellites, identify the flux components with the largest discrepancies, and investigate the reasons for the discrepancies. An ancillary objective is to compute the local (one-dimensional) oceanic budgets of heat and momentum and determine the degree to which these budgets are locally balanced.

Accomplishments

Three Air-Sea Interaction Meteorology (ASIMET) systems were assembled and tested. Two systems, comprised of the best performing sensors, were mounted on a three-meter discus buoy in preparation for deployment. A mooring turn-around cruise was conducted on the WHOI ship Oceanus in order to retrieve the existing mooring (NTAS-2, deployed 4 March 2002) and replace it with the new mooring (NTAS-3). The NTAS-3 mooring was deployed at 14º 49.5' N, 51º 01.3' W on 15 February 2003. The NTAS-2 mooring was recovered from 14º 44.5' N, 50º 57.0' W on 16 February. The period between deployment and recovery was dedicated to an intercomparison of the two systems, with the shipboard system as an independent benchmark. To ensure high-quality meteorological data, all NTAS-3 sensors were calibrated prior to deployment, and NTAS-2 sensors will be post-calibrated. A cruise report is in preparation.

Preliminary processing of the NTAS-2 meteorological data has been completed. Data return was excellent, with all sensors operating for the complete deployment period. The intercomparison period showed very encouraging results, indicating little degradation of NTAS-2 sensor performance after one year at sea. After post-calibration of the sensors, the corrected, 1-min data will be used for further analyses. The uncorrected, hourly Argos data are available on-line from the Upper Ocean Processes (UOP) group web site (http://uop.whoi.edu/ntas). To date, 5 months of hourly meteorological data from NTAS-3 are also available for examination on the UOP web site. Preliminary evaluation indicates that all NTAS-3 sensors are performing as expected.

Using supplemental funding from the WHOI Ocean and Climate Change Institute, it was possible to outfit the NTAS-2 and NTAS-3 moorings for oceanographic measurements in the upper 150 m. Ten high-resolution (0.005 C) temperature sensors were deployed between 5 and 80 m depth with 5-10 m vertical resolution. Seven low-resolution (0.1 C) temperature sensors were deployed between 90 and 150 m depth at 10 m intervals. A single-point acoustic current meter and a 300 kHz ADCP (uplooking) were deployed at 6 m and 100 m, respectively. All but one of these sensors returned full records from NTAS-2. These data will allow the local heat balance to be investigated for the NTAS-2 period.

The NTAS-1 mooring was deployed in March 2001 and recovered in March 2002. Meteorological sensors from the NTAS-1 deployment have been post-calibrated, and NTAS-1 data have been post-processed. Hourly averaged data from the resulting data set have been posted on the UOP web page. The 1 min data are being used as the basis for air-sea flux computations using bulk formulas. Some aspects of the flux computation (e.g., parameter settings for the COARE bulk flux algorithm and the influence of temporal averaging) are presently being evaluated in the process of producing a final flux data set.

NOAA Progress Report

Variability of Thermohaline Circulation and Freshwater Storage in the Arctic Ocean

NOAA Grant: NA17RJ1223
July 1, 2002 – June 30, 2003

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Program Manager: John Calder, Director Arctic Research Office, NOAA Oceanic and Atmospheric Research R/AR

The major goal of this project is to investigate the variability of the thermohaline circulation and freshwater storage in the Arctic Basin under the influence of different climate regimes based on analysis of existing data and numerical modeling.

Project objectives are to:

- Determine and document the variability of fresh water storage and thermohaline circulation of the Arctic Ocean;

- Identify the ocean response (freshwater storage and thermohaline circulation) to the seasonal, interannual and the apparent 10-15-year cycle of atmospheric circulation modes (Proshutinsky and Johnson, 1997) in the Arctic.

Project scientific questions are:

What is the mechanism for accumulation of fresh water in the center of the Beaufort Gyre?

Is this fresh water transported to the North Atlantic and what are the conditions that influence its rate of transport?

What is the primary driver of the Arctic Ocean circulation, thermohaline or wind-driven forcing?

How does the wind-driven circulation change the thermohaline structure and resultant circulation seasonally, annually, and decadally?

Project Results

During the second year of research we have developed annual grids of the Arctic Ocean water temperature and salinity in the upper 500 meter layer using methods of optimal data reconstruction based on EOF techniques. This work was mainly done by the team of the Arctic and Antarctic Research Institute in St. Petersburg, Russia. We have also examined interannual

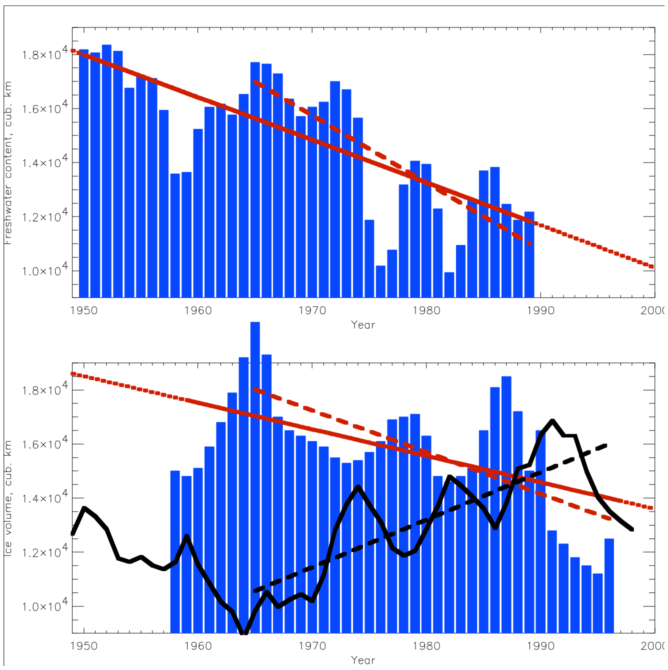


Figure 1. Upper panel: Freshwater content in the Arctic Ocean relative to salinity 31.5. The data are from the Arctic and Antarctic Research Institute data archives. Lower panel: Variability of simulated sea ice volume in the Arctic Ocean (Ruediger Gerdes and Cornelia Koeberle personal communications) Solid lines show linear trends based on the time series analysis and dotted lines show projections based on original linear trends. Dashed lines show linear trends based on time series starting from 1965 (maximum FW content including ice and water in the ocean) Black solid and dashed lines show NAO and NAO trend since 1965, respectively. (NAO index is multiplied by 1.E4 in order to be compared with other variables). One sees that FW content and sea ice volume correlate with the NAO very well.

variability of these parameters with respect to freshwater storage changes for the period 1948-1993 (see Figure 1).

The second direction of our research was modeling. To efficiently use the resources and to focus on a specific question, we employed a hierarchy of models, ranging from a box model (Dukhovskoy et al., 2003), an idealized 3-D model (Proshutinsky et al., 2002) and a 3-D coupled ice-ocean model (Hakkinen and Proshutinsky, 2003).

Some results of modeling are shown in Figure 2. One sees that wind-driven circulation generates at least 3 major gyres in the Arctic Ocean and GIN Seas. We assume that these Gyres are important players in the decadal Arctic climate variability and that the fresh water and heat exchange among these Gyres are very important.

Figure 2 shows typical simulated wind-driven ice and surface water circulation in the Arctic Ocean and Nordic Seas (Proshutinsky and Johnson, 1997; Proshutinsky, 2003). One sees that depending on the circulation regime, the Beaufort, Greenland, Labrador, and Irminger Sea Gyres change their intensity. The Beaufort Gyre wind-driven surface circulation can even change its direction of rotation (Proshutinsky and Johnson, 1997; Rigor et al., 2002) but the Greenland, Labrador and Irminger Sea Gyres are always cyclonic but could be weaker or stronger. Figure 3 explains hypothetical interactions among these gyres.

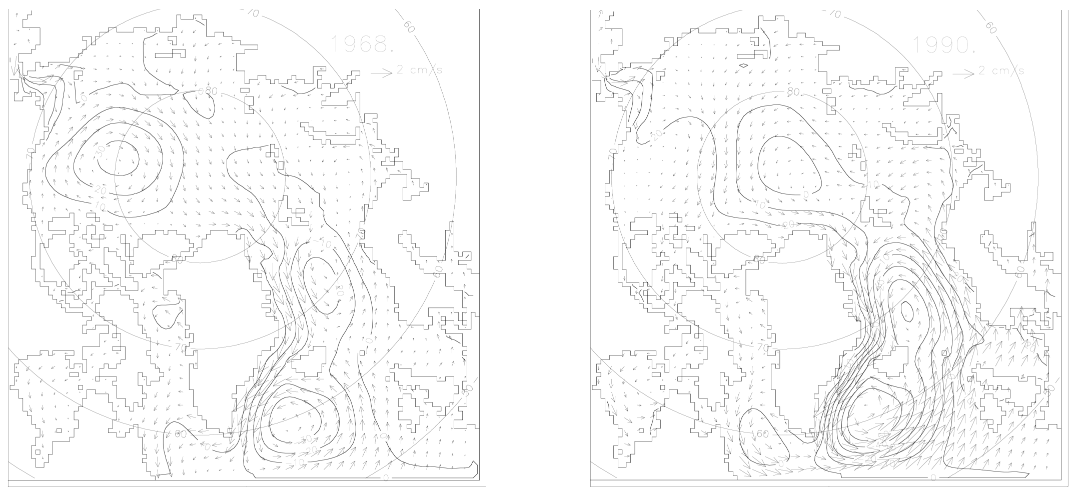
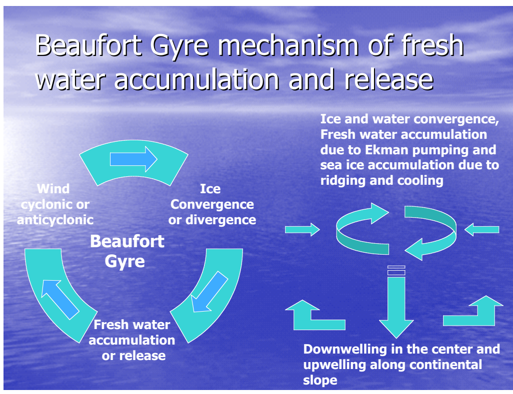
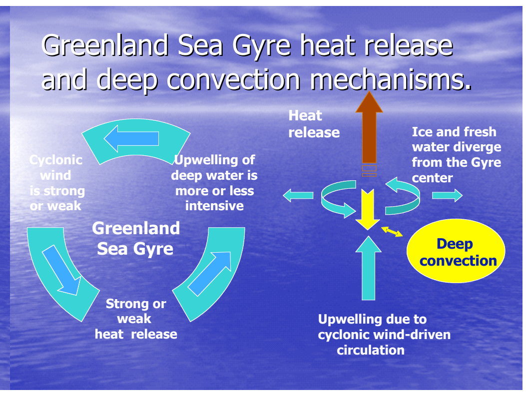


Figure 2. Ice drift and surface currents for the typical anticyclonic (high NAO/AO index) circulation regime conditions (left panel) and typical cyclonic (low NAO/AO index) circulation regime conditions (right panel) Black line shows sea surface heights (cm). These are simulated results of the wind-driven circulation (see Proshutinsky and Johnson, 1997 for more details).

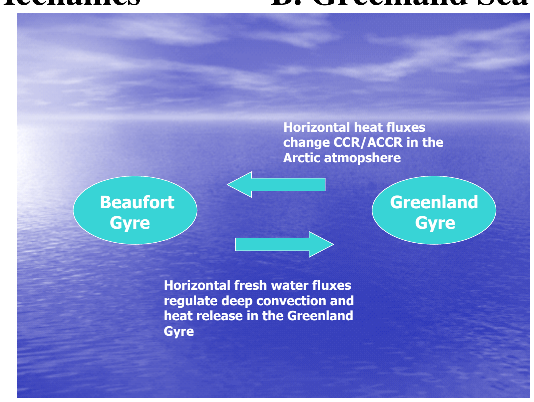
In order to check these mechanisms we employed a box model of the Arctic System. The box model of The Arctic-Nordic Seas system consists of several boxes including a time-dependent, one-dimensional model of the Arctic Ocean and shelf that is coupled with a thermodynamic ice model and interacts with a one-dimensional model of the Nordic Seas to explore interannual variability of the Arctic Ocean – Nordic Seas system. Periodical solutions preliminary obtained with seasonally varying forcing for the cyclonic (high NAO index) and the anticyclonic (low NAO index) Arctic Ocean circulation regimes reproduce major anomalies in the ocean thermohaline structure, sea ice volume, and fresh water fluxes attributed to these regimes. The correlation between the freshwater flux from the Arctic Ocean and deep convection in the Greenland Sea reproduced in the model suggests that the hypothesized freshwater storage and release mechanism may be significant for explaining Arctic Ocean decadal variability. This model was employed in our studies because it allows us to test our hypothesis from a very general view point but it is important that we will be able to test numerous scenarios of system behavior without limitations related to uncertain forcing, initial conditions, resolution, computer resources, etc. which usually characterize problems of the numerical regional or global models.

In order to test different ideas related to oceanic physics and interactions between sea ice and ocean we have employed a version of Sirpa Hakkinen model (Hakkinen, 1993). The previous Arctic Ocean model simulations have revealed that the Arctic Ocean has a basin wide oscillation with cyclonic and anticyclonic circulation anomalies (Arctic Ocean Oscillation; AOO) which has a prominent decadal variability (Proshutinsky and Johnson, 1997). In our study here we explored how the simulated AOO affects the Arctic Ocean stratification and its relationship to the freshwater variability including sea ice cover variability input. Our focus was to investigate the competition between ocean dynamics and ice formation/melt on the Arctic basin-wide fresh water balance. We have found that changes in the Atlantic water inflow can explain almost all of the simulated fresh water anomalies in the main Arctic basin. The Atlantic water inflow anomalies are an essential part of AOO, which is the wind-driven barotropic response to the Arctic Oscillation (AO). The baroclinic response to AO, such as Ekman pumping in the Beaufort Gyre, and ice melt/freeze anomalies in response to AO are possibly less significant considering the whole Arctic fresh water balance.





A. Beaufort Sea Mechanics **B. Greenland Sea processes**



C. Arctic-Nordic Seas interactions

Figure 3. Hypothetical interactions between the Arctic Ocean and the Nordic Seas through FW and heat exchange. Depending upon the predominant atmospheric circulation regime (anticyclonic/cyclonic or low/high NAO indexes) the Beaufort Gyre accumulates or releases FW and the Arctic Ocean accumulates or releases sea ice. The Greenland Sea Gyre accumulates or releases heat to the atmosphere depending on intensity of the atmospheric circulation and FW flux from the Arctic Ocean and influences intensity of heat flux to the Arctic Ocean and ultimately changes circulation regime of the Arctic atmosphere from cyclonic to anticyclonic or from anticyclonic to cyclonic. Current studies of this mechanism, using a relatively simple box modeling approach (Dukhovskoy, Johnson and Proshutinsky, 2003) show that this mechanism could work providing auto oscillations in the system with periods from 10 to 20 years depending on model internal parameters and variations of external forcing (solar radiation, cloudiness, precipitation minus evaporation, etc.)

Project Publications and Presentations

Papers:

Proshutinsky, A.Y. , R.H. Bourke, F. McLauglin The role of the Beaufort Gyre in the Arctic climate variability: seasonal to decadal climate scales, Geophys. Res. Lett., 29(23), 2100, doi:10.1029/2002GL015847, 2002. This paper was prepared earlier but was **published** in December 2002.

Proshutinsky, A. , Circulation of the Arctic Ocean from observations and model results, In:Arctic environment variability in the context of global change, Kondratyev, K. Y., O.M. Johannessen, L.P. Bobylev, (eds). **accepted** for publication by Praxis publishing house (Great Britain), March, 2003

Hakkinen, S., A. Proshutinsky, Heat and salt content variability in the Arctic Ocean, JGR (**accepted**)

Steiner, N., G. Holloway, S. Hakkinen, D. Holland, M. Karcher, W. Maslowski, A. Proshutinsky, M. Steele, J. Zhang, Comparing modeled streamfunction, heat and freshwater content in the Arctic Ocean, Elsevier Science, Ocean Modelling, 2003. (**accepted**)

Proshutinsky, A., Decadal scale signals in the Arctic's atmospheric and oceanic systems, Seventh Conference on Polar Meteorology and Oceanography and Joint Sympsoium on High-Latitude Climate Variations, Hyannis, May, 2003, **Abstract**.

Petteri Uotila, David M. Holland, Sirpa Häkkinen, Greg Holloway, Nadja Steiner, Michael Steele, Jinlun Zhang, and Andrey Proshutinsky, An Energy-Diagnostics Intercomparison of Coupled Ice-Ocean Arctic Models, Seventh Conference on Polar Meteorology and Oceanography and Joint Symposium on High-Latitude Climate Variations, Hyannis, May, 2003, **Abstract**.

Hakkinen, S., A. Proshutinsky, Heat and salt content variability in the Arctic Ocean, EGS meeting, April 2003, Nice, France, **abstract**.

Dukhovskoy, D., M. Johnson, and A. Proshutinsky, Model Studies of Fresh Water Fluxes in the Arctic Ocean, 2002 Fall Meeting, **abstract**.

Talks:

“Freshwater accumulation and release mechanism and role of the Beaufort Gyre in the Arctic Climate Variability", First International PARTNERS Workshop ``Pan-Arctic River Transport of nutrients, Organic Matter, and Suspended Sediments”, 24-26 February 2003, Marine Biological Laboratory, Woods Hole, MA, USA (**invited**).

“Decadal scale signals in the Arctic's atmospheric and oceanic systems”, American Meteorological Society 7th Polar Conference on Polar Meteorology and Oceanography, May 12-16, 2003, Hyannis (**invited**).

"The role of the Beaufort Gyre in the Arctic climate variability: seasonal to decadal climate scales". Chapman Conference on High-Latitude Ocean Processes, 26-29 August 2002 (**invited**).

University of New Hampshire Chapman seminar: “Sources and sinks of freshwater in the Arctic Ocean”, February 20-21, 2003, Durham, New Hampshire (**Invited**)

References:

Hakkinen, S., A. Proshutinsky, Heat and salt content variability in the Arctic Ocean, JGR (accepted)

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Proshutinsky, A.Y. , R.H. Bourke, F. McLauglin The role of the Beaufort Gyre in the Arctic climate variability: seasonal to decadal climate scales, Geophys. Res. Lett., 29(23), 2100, doi:10.1029/2002GL015847, 2002.

NOAA Progress Report

Sources of the Cold Tongue in the Eastern Tropical Pacific Ocean

NOAA Grant: NA17 RJ1223
July 1 2002 – June 30, 2003

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Research Activities and Results

The overall goal of this research is to make data--based models of the mean and seasonal or interannual cycles of the eastern tropical Pacific ocean circulation. The primary aim of the project is to locate and quantify the circulation components that contribute to the cold tongue. This project is a collaboration between Dr. Sloyan (WHOI) and Drs. Johnson and Kessler (NOAA/PMEL). The original grant began in February 2000, when Dr. Sloyan arrived at PMEL. In August 2001 Dr. Sloyan officially began employment at WHOI, and in November 2001 physically moved to from PMEL to WHOI. The collaboration on this project among Drs. Sloyan, Johnson and Kessler continued after Dr. Sloyan moved to WHOI and a final manuscript is now nearing completion.

Dr. Sloyan is responsible for the development, implementation and analysis of the core inverse model of this work. The first component of the study, formulating the mean inverse model, using CTD/ADCP sections, CTD and XBT data, as well as wind and air--sea flux climatologies showed that the tropical Pacific can be divided into three distinct regions: western; central; and eastern. In the western region the Equatorial Undercurrent and subsurface countercurrents develop. In the central and eastern regions the shallow tropical cells are seen. The Pacific cold tongue in the eastern region results from diapycnal upwelling through all layers of the Equatorial Undercurrent, which preferentially exhausts the lightest (warmest) layers of the Equatorial Undercurrent between 125W and 95W, allowing the denser (colder) layers to upwell east of 95W and adjacent to the American coast (Sloyan et al., 2003). This work also highlighted the role of the cold tongue in the interhemispheric transport.

In the last 12 months Dr. Sloyan has developed an interannual ENSO inverse model. This model has resolved the evolution of the currents and circulation across the tropical Pacific Ocean, and the effect of this circulation on the cold tongue during a composite 1990's ENSO cycle. ENSO modulates the currents of the tropical Pacific, in particular the SEC(N,S) are weaker than normal in the western and central Pacific, and surface westward current develop in the western and central Pacific. Only a small reduction to the EUC transport and a slight increase in the transport of the NSCC in the western tropical Pacific are seen. Surface transport on the western warm pool moves the warm water pool into the central Pacific, which is advected into the eastern region at the end of the ENSO year+0 (Sloyan et al. 2003). The manuscript describing the results of this model will be submitted shortly.

Dr. Johnson's primary responsibility was analysis of the CTD/ADCP data from TAO cruises that are a vital component of this project. During the early part of this project, Dr. Johnson finished up work using these data to study the mean velocity, divergence, and upwelling in the cold tongue (Johnson et al., 2001). He also contributed to a study using ADCP data, TAO winds, and scatterometer stress estimates to show how tropical ocean currents can play an important role in modifying air-sea momentum fluxes (Kelly et al., 2001), to a study that used the TAO mooring data for a novel look at seasonal and interannual variability of equatorial upwelling (Meinen et al., 2001), to a review of global tropical ocean circulation (Godfrey et al., 2001), especially the Pacific and Indian basins, and to a study comparing and contrasting tropical circulation in the Atlantic to the Pacific (Molinari et al., 2003). He used the surface drifter data to look at the surface pathways and time scales of flow in the Pacific subtropical cell, as well as patterns of equatorial divergence related to the cold tongue and the tropical cells (Johnson, 2001). He used the CTD/ADCP sections to analyze the mean, seasonal, and interannual variability of the zonal currents and water property structure across the entire tropical Pacific (Johnson et al., 2002b). He also used the two-decade long historical deep CTD data record to revisit the Pacific Equatorial Deep Jets, finding very long temporal and zonal coherence for these features, as well as significant but very slow downward vertical propagation (Johnson et al., 2002a). Most recently he has contributed to a study using the velocity information from the CTD/ADCP data to explain how the zonal currents in the equatorial Pacific modify Rossby wave dynamics, allowing an asymmetric response in the annual Rossby wave, as observed with altimeter data (Chelton et al., 2003).

Dr. Kessler has worked with the historical XBT and CTD data that are vital to the east Pacific inverse, and showed that the NE tropical Pacific (essentially the EPIC region of interest) is a region of strong off-equatorial upwelling that contributes significantly both to mean SST patterns and to the general circulation of the Pacific (Kessler, 2002). This work also showed that OGCM models of the Pacific forced by climatological winds typically develop an unrealistic discontinuity in the NECC in the central Pacific. Examination of the reasons for this show that the error is due to poor resolution of the ITCZ curl, which is too weak and too broad in in situ products, and that scatterometer wind forcing produces a more realistic NECC simulation. He also helped to study annual and ENSO modulation of near-surface stratification and the diurnal cycle of SST based on high resolution time series from the 0, 110W TAO mooring (Cronin and Kessler

2002). During final stages of the El Nino of 1997-98, the establishment of shallow barrier layers allowed warm conditions to persist at 110W, even as the thermocline shoaled. Recently, using the ADCP velocity data as well as satellite winds and a numerical moded, he showed that the Pacific South Equatorial Current is amplified by curl due to east Pacific air-sea interaction, and by nonlinear vorticity advection (Kessler et al, 2003). He is also working on a review of the eastern tropical Pacific circulation (Kessler 2003).

Publications and Presentations of Results Fully or Partially Supported by this Grant

Chelton, D. B., M. G. Schlax, J. M. Lyman, and G. C. Johnson. 2003. Equatorially trapped Rossby waves in the presence of meridionally sheared baroclinic flow in the Pacific Ocean. Progress in Oceanography, 56, 323-380.

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Sloyan, B. M., G. C. Johnson, and W. S. Kessler. 2003. The Pacific Cold Tongue: A pathway for interhemispheric exchange. Journal of Physical Oceanography, 32, 1027-1043.

Sloyan, B. M., G. C. Johnson, and W. S. Kessler. 2003. Modulation of the Equatorial Pacific Circulation during a 1990's composite El Nino-Southern Oscillation cycle, in preparation.

Sloyan, B. M. and J. Schroeter. 2001. Correlation of ocean mass and temperature fluxes among hydrographic sections in the southern oceans. Geophysical Research Letters, 28, 2049-2052.

Presentations

Dr. Sloyan has presented seminars on the work support by this grant at the University of Washington, Florida State University, Scripps Institute of Oceanography and Woods Hole Oceanographic Institution. She also presented posters at the CLIVAR Workshop on Shallow Tropical/Subtropical Overturning Cells (STC) and their interaction with the atmosphere, Venice and WOCE/JGFOS Ocean Transport meeting, Southampton UK.

Dr. Johnson has presented seminars on this work at the University of Washington, the Goddard Space Flight Center, the Woods Hole Oceanographic Institution, and Oregon State University. He has presented posters and/or given talks at the CLIVAR Workshop on Shallow Tropical/Subtropical Overturning Cells (STC) and their interaction with the atmosphere in Venice, the WOCE/JGFOS Ocean Transport meeting in Southampton, the AGU/ASLO Ocean Sciences Meeting, and the WOCE and Beyond Conference in San Antonio.

Dr. Kessler has presented seminars on this work at University of Washington, Scripps Institute of Oceanography, Oregon State University, NCAR, Lamont-Doherty Earth Observatory of Columbia University, Flinders University of South Australia, CSIRO Division of Marine Research, Australia, Woods Hole Oceanographic Institution, CICESE, KNMI, the University of Hawaii, the AGU Fall Meeting, and the EGS Joint Assembly in Nice.

NOAA Progress Report

Air-Sea Interaction in the Eastern Tropical Pacific ITCZ/Cold Tongue Complex.

NOAA Grant: NA17RJ1223
July 1, 2002 to June 30, 2003

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Program Manager: Mike Patterson, Office of Global Programs

As part of the NOAA funded Pan American Climate Study (PACS), two surface moorings were deployed, one at the 3° S (cold tongue) and one at 10° N, the Inter-Tropical Convergence Zone (ITCZ) on 125° W. Each surface buoy carried two complete sets of meteorological sensors (wind velocity, air and sea temperature, incoming shortwave radiation and incoming longwave radiation, humidity, barometric pressure, precipitation, surface currents), and the heat, mass; and momentum fluxes have been computed via the bulk formulae (Figures 1. and 2.). The mooring lines carried temperature, conductivity, and velocity sensors to observe upper ocean variability in the upper 200 m. The data from the northern mooring returned the first accurate and complete time series of the air-sea fluxes of heat, freshwater, and momentum in the eastern Pacific warm pool beneath the northernmost climatological position of the Inter-Tropical Convergence Zone (ITCZ). This data set is also unique because it spans the strong El Niño event of 1997-98 and the onset of the subsequent La Niña. The data set was the focal point for the thesis work of an MIT/WHOI graduate student (Farrar, 2003), who has recently defended the thesis and is currently preparing results for publication under the supervision of Weller.

The effort was aimed at quantifying the relative importance of various physical processes in the evolution of upper ocean thermal structure and sea surface temperature at the mooring site. Drawing on the surface and subsurface mooring observations and remotely sensed wind and sea surface altimetry, the analysis showed that horizontal advection was of secondary importance in producing the observed thermal evolution. Instead, the most important factors in upper ocean thermal evolution were surface heat and momentum fluxes, vertical advection associated with Ekman pumping, and episodic vertical mixing across the thermocline associated with enhancement of the vertical shear by the large-scale geostrophic flow field. Vertical mixing was particularly important at the site during the transition of the tropical Pacific from El Niño to La Niña conditions. These findings yield insight into the factors affecting SST in the eastern Pacific warm pool, as the observed thermal evolution at the mooring site was representative of a much larger pattern of variability that has been shown to be a reliable precursor to ENSO phase transitions (c.f. Meinen and McPhaden, 2000, 2001; Alory and Delcroix, 2002).

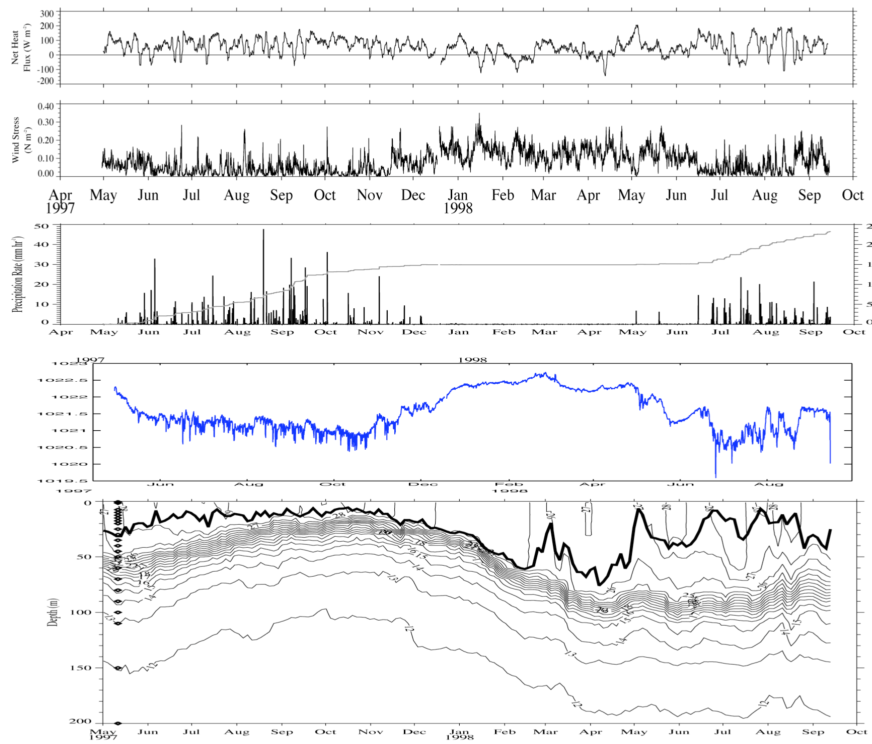

Figure 1. Summary of 18 months of surface forcing at 10°N, 125°W, showing time series of the net heat flux, the magnitude of the wind stress, rainfall rate and integrated precipitation, surface density and an overplot of mixed layer depth and select isotherms.

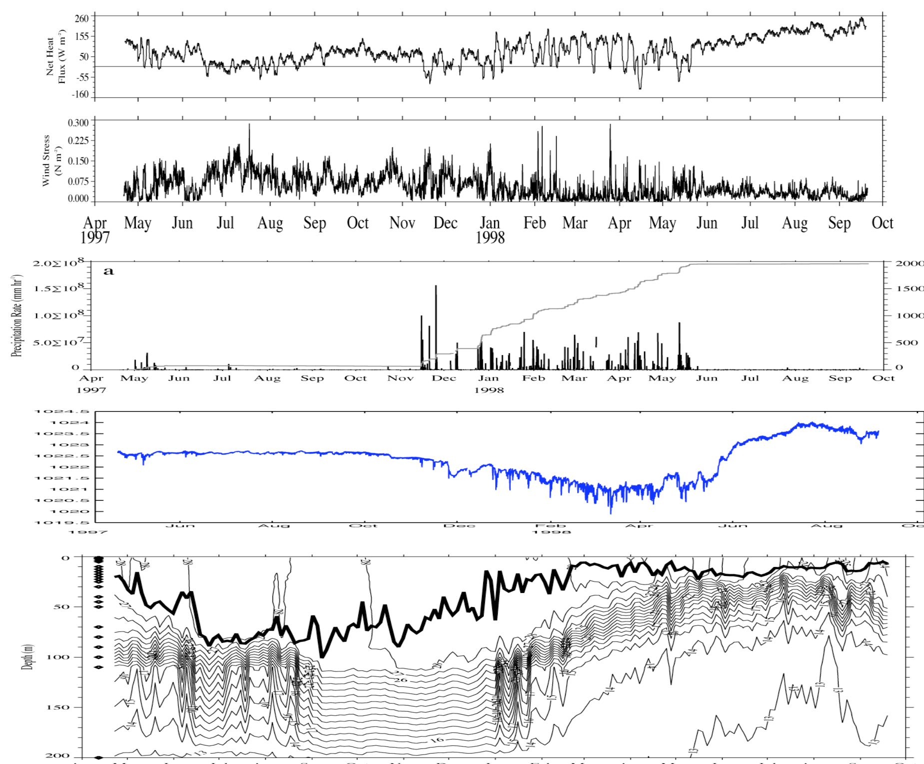

Figure 2. Summary of 18 months of surface forcing at 3°S, 125°W, showing time series of the net heat flux, the magnitude of the wind stress, rainfall rate and integrated precipitation, surface density and an overplot of mixed layer depth and select isotherms.

Another important focus of this effort was to quantify the local air-sea fluxes of heat, freshwater, and momentum and to assess the importance of various timescales (from diurnal to seasonal) in the variability of these fluxes. This work led to several significant significantly reduce the solar heat flux. While the solar heat flux was appreciably reduced during ITCZ conditions, the larger net heat flux was due to a relatively low evaporative heat loss from the sea surface during ITCZ conditions. This decreased evaporative heat loss is associated with reduced mean wind speeds and increased relative humidity during ITCZ conditions. At shorter timescales (2 to 30 days), there were also important differences between the ITCZ and non-ITCZ seasons. During ITCZ conditions, most of the 2 to 30 day variability in the net heat flux was due to variations in solar heat flux, while during non-ITCZ conditions, most of the 2 to 30 day variability in net heat flux was due to variations in latent heat flux. Farrar and Weller compared of the high quality meteorological data from the buoy to surface fields from the European Centre for Medium Range Weather Forecasting (ECMWF), National Center for Environmental Prediction (NCEP), and Southampton Oceanography Centre (SOC) and noted the drawbacks of using these as proxies for the surface forcing.

Analysis of the 10°N data has just been completed in conjunction with a successful Master's Thesis. The 10°N analysis showed that most important in upper ocean thermal evolution were surface heat and momentum fluxes, vertical advection associated with Ekman pumping, and episodic vertical mixing across the thermocline associated with enhancement of the vertical shear by the large-scale geostrophic flow field. Vertical mixing was particularly important during the transition of the tropical Pacific from El Niño to La Niña conditions. Another goal is to quantify the local air-sea fluxes of heat, freshwater, and momentum, to assess the importance of various timescales (from diurnal to seasonal) of surface forcing, and to compare the observed fluxes with those from climatologies, models, and remote sensing (Figure 3.). Seasonally the net heat flux into the ocean was 50 to 100 W m^{-2} larger under the ITCZ. With the ITCZ overhead, most of the 2 to 30 day variability in heat flux was due to variations in solar heat flux, while during non-ITCZ conditions most of the 2 to 30 day variability in net heat flux was due to variations in latent heat flux..

Continuing progress will allow for the completion of the analysis of the data collected at 125°W during 1997-1998 in conjunction with preparation of a Ph. D. Thesis. The effort will first shift to examining the surface forcing, upper ocean dynamics, and evolution of the thermal structure at 3°S. With that complete, we will use remote sensing and TAO data in conjunction with the upper ocean observations and air-sea fluxes from the two mooring sites to extend the effort to identify the important physical processes that drive the evolution of SST and upper ocean thermal structure over the broader region spanning the equatorial cold tongue and in the eastern Pacific warm pool during the El Niño and La Niña events of 1997-98.

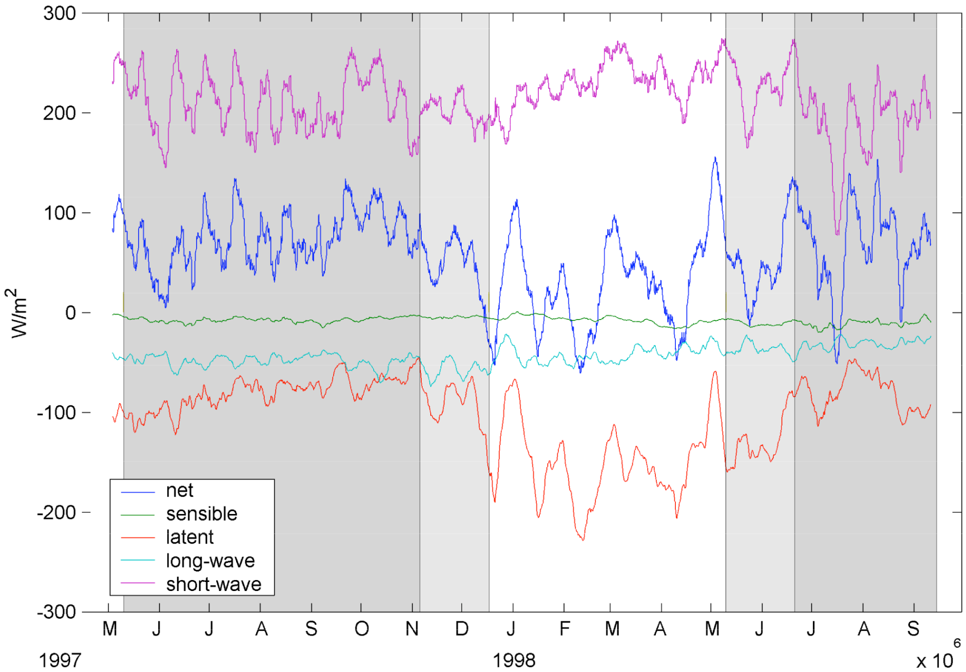

Figure 3. Heat flux component time series at 10°N. Times when the ITCZ was present are shaded.

References:

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NOAA Progress Report

Implementation of One High Density XBT Line with TSG and IMET Instrumentation in the Tropical Atlantic

NOAA Grant: NA17RJ1223
July 1, 2002 to June 30, 2003

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This is the summary technical report on a program to implement one high-density XBT line with TSG and IMET Instrumentation in the tropical Atlantic.

1. Project Goals – Year 2.

The Year 2 tasks were to complete fabrication and to install the system on the VOS specified by NOAA-SEAS for NOAA-AOML. Six months later the system was to be turned around using the second system. These goals are delayed as noted in the following Description of Work.

2. Description of Work – Year 2.

The two systems (designated AIA1 and AIA2 for AutoImetAtlantic1 and 2) have been completed, calibrated and burned-in on the bench at WHOI. They are ready for installation on the selected VOS. Batteries have been purchased and are on hand.

Interface with the NOAA-SEAS office in Silver Spring, MD has gone well and the SEAS 2000 system with AutoIMET is working well on the bench. WHOI provided a test bow mast logger and radio modem for NOAA-SEAS (Janet Brockett) to use in her software development and test.

Ship selection has not been made. While the Lykes Winner was visited last summer and Steve Cook has obtained permission of the ship owners for the installation, it was determined by WHOI not to be suitable for a first time installation of a new system.   The factors involved are as follows:

1) The scientific value is low since the trip cycle time is 11 weeks and the high density XBT runs are not made on a consistent basis. The alternate to use a ship from SafMarine (low density XBT runs only) would have been much better but that ship was removed from service last fall.

2) The logistics are unsuitable due to the short in-port times scheduled. After the run from Cape Town, the ship is in NY for (approx) 5 hours, Montreal for 2 days then to Hamilton and back to Montreal for 2 days (but mega custom problems for shipping equipment), then sometimes in NY for 5-6 hours, into Philadelphia for 6-8 hours, and finally to Charlestown for 5-6 hours.   An installation might be done over several cycle times in warm weather but not in cold weather. Turnarounds could be done in these times if the weather was reasonable.

3) A special consideration - this is the first installation of a new system and the system reputation will depend on its good performance. Jim Farrington and I were told by the Third Mate to leave the ship when we were coming on board to visit the Captain at the start of our visit last summer but after lunch the Chief Mate ushered us to the Captains cabin. While the attitude of the Captain was excellent, the crew was not friendly. It was not a comfortable ship to be on.

The plan now is to install AutoIMET on the Columbus Florida in June (part of the CORC program) with excellent ship cooperation and very excellent support from Carrie Wolfe of the Southern California Marine Institute (she is also the official VOS coordinator in Long Beach). Some of the learning curve for a new system can take place in a good environment.

The search for an alternate ship will take place when Steve Cook is in Europe in July 03 for meetings with the corporate offices of several shipping companies. This will hopefully result in a more suitable ship for the Atlantic VOS.

NOAA Progress Report

Long Term Evolution and Coupling of the Boundary Layers in the Stratus Deck Regions of the Eastern Pacific (Stratus)

Grant: NA17RJ1223
July 1, 2002 to June 30, 2003

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Background/Objectives

The remarkably persistent stratus decks to the west of Peru and Chile exert a strong cooling influence on the local and global heat balance, as verified in recent experiments with ocean and coupled models. However, there have been few measurements of tropical and Peruvian stratus decks. The weak observational foundation is currently limiting our ability to better understand and model this region. Thus, an observational focus on eastern Pacific stratus was recommended for the EPIC (Eastern Pacific Investigation of Climate) program.

The mooring is a central element of EPIC and revolves around the deployment of a well-instrumented air-sea interaction surface mooring under the stratus clouds off northern Chile. The immediate goals of the deployment are to obtain time series of: accurate air-sea fluxes and surface meteorology, the temporal evolution of the vertical structure of the upper ocean temperature and salinity, and horizontal velocity fields

The goals of the analyses of this data will be to: examine the temporal evolution of the upper ocean heat content, quantify the roles, at time scales from minutes to seasonal, of atmospheric forcing, and local, 1-D process in that evolution, investigate how the atmosphere drives the ocean under the stratus deck, examine the relative importance of shortwave, longwave, and latent heat flux variability related to the cloud cover, and explore the possible feedback mechanisms that would link the evolution of the atmospheric and oceanic boundary layers.

In addition, after calibration, the data will be made available and used in ground-truthing remote sensing, as benchmark time series for atmospheric, oceanic, and coupled models, and to develop improved air-sea flux fields in that region.

The surface mooring that was originally deployed in October 2000 has now been successfully recovered and redeployed twice. The most recent mooring cruise was aboard the R/V Melville from October 9-30, 2002. The cruise which departed from Puntarenas, Costa Rica and arrived in Arica, Chile involved the turn around of the mooring as well as a number of CTD stations along 20° S between the mooring and Arica. The cruise participants include observers from the Chilean Servicio Hydrografico y Oceanografico de la Armada and collaborators from the University of Concepcion. The mooring maintenance and cruise work is now covered under a separate proposal, as an Ocean Reference Station for GOOS.

Recent Work

Over the past year (7/1/2002 - 6/30/2003) the major activities have been preparation of the cruise report documenting the deployment cruise, monitoring and sharing the meteorological data telemetered from the mooring via Service Argos, preparation for and participation in the third cruise in October 2002, and calibration and processing of the data recovered from the first two deployments.

In September 2002, Lara Hutto took over the responsibility for data calibration, processing and archiving. The mooring contains over 50 specialized instruments which all need to be assessed individually and inter-compared to assure that the data is reliable. The first two years of STRATUS data have now been processed, in a consistent manner, and merged to form gridded time-depth arrays of relevant oceanographic properties (e.g. temperature, salinity, velocity). The atmospheric data has been cleaned and the two redundant sensor systems inter-compared to identify errors. The atmospheric instrumentation for the upcoming year also needs extensive pre-deployment calibration. The processed data is archived on CD for future use and dissemination. We also maintain a web site (uop.whoi.edu/stratus/archival_data.html) where the data is freely available for download.

In May 2003, a postdoctoral investigator, Keir Colbo, was hired to work exclusively on the STRATUS project. Detailed initial analysis of the oceanographic data has lead to a partial redesign of the sub-surface portion of the mooring to be deployed in November 2003. The new mooring will include additional temperature/conductivity and current meters situated in and below the thermocline(halocline). The goals of the new instrumentation are to better quantify the exchange of heat and salt between the upper ocean mixed layer and the underlying salinity minimum and also to better resolve the velocity structure immediately within and below the permanent thermocline. CTD casts near the mooring show that the sharp thermocline(pycnocline) located between 150m and 200m depth is likely to support strong double diffusive instabilities (salt fingering). The ocean is strongly evaporative at the mooring site and thus salt must be exported out of the mixed layer on an annual basis. The role of advection, both within the mixed layer and below it in the salinity minimum, and the importance of double diffusive processes need to be better understood in order to adequately predict mixed layer depths and consequently sea surface temperatures (SSTs). The additional velocity measurements will also enable a better prediction of advection and a more definitive way to identify the signature of eddies that pass through the mooring location.

A summer student, Matthew Littleton, was also hired in May 2003 to assess the effects of low wind periods on the STRATUS data set. The 1-D PWP mixed layer model was initialized with observations from CTD stations at the mooring site and forced with the observed meteorology. Results of this analysis are pending.

To fulfill our requirements to the U.S. Department of State and to Chile for granting permission to sample within up to 12 miles from the coast, we submitted in January, 2003 a detailed cruise report [WHOI Technical Report WHOI-2003-01]. We had previously supplied the national observers with a CD-ROM of all the data collected during the cruise and of the software needed to read that data.

Future Work

Now that we have steady funding, and with the inclusion of a dedicated postdoctoral investigator, we expect to make quick progress on the scientific questions that initiated this study.

In the short-term the analysis will shift to the relation between the SST and the cloud cover. Direct measurements of both allow us to examine lag/lead correlations and examine the degree to which the clouds respond to SST (or the SST responds to cloud cover). The SST is also influenced by the advection of water from further south and onshore. The nature of this advection (e.g. episodic versus steady) needs further clarification. To help address this and to better understand the dynamics of the salt budget a one-dimensional model of the upper ocean, that includes the physics of double diffusion, will be initiated and forced with the observations.

As the data record grows in length we are also better situated to respond to questions about the interanuual time scales and the effects of El Nino oscillations, including Rossby wave propagation through our mooring location.

NOAA Progress Report

U.S. Program in Marine Biotoxins and Harmful Algae

NOAA Grant: NA17RJ1223
July 1, 2002 – June 30, 2003

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The following summary lists activities conducted by the National Office during the second year of this cooperative agreement:

International Activities:

- *International Council for the Exploration of the Sea (ICES) National Coordinating Center for Exchange of Information on Harmful Algal Blooms.* Compiled reports of all HAB events in U.S. for the year 2002 for ICES Coordinating Center for Exchange of Information on HABs. This is the only compilation of US HAB incidents.

- Attended ICES Working Group on HAB Dynamics meeting in Aberdeen, Scotland and presented summary of U.S. bloom events. Gave a presentation on "The EU-US Programme on Harmful Algal Blooms: A Joint Initiative by the European Commission – Environment and Sustainable Development Programme and the US National Science Foundation".

- Collated and prepared maps for all U.S. HAB events for inclusion in a "global and visual overview of harmful events for the preceding 10 years". This is an ICES GIS effort, and now is an annual activity. Examples of these maps are included on the US National HAB web page.

- Served as a depository and North American distribution center for the Proceedings of the *9th International Conference on Harmful Algal Blooms* and the *8th International Conference on Toxic Marine Algae* (published by IOC). Also distributed copies of *Monitoring and Management Strategies for Harmful Algal Blooms in Coastal Waters* (published by APEC and IOC). Handled payments and mailings for all requests for these books.

- Assisted with editing and obtaining reviews for papers submitted for the Proceedings from the *Second International Conference on Harmful Algae Management and Mitigation* (HAMM) held in Qingdao, China November 12-16, 2001.

- Served on Planning Committee for a joint US – European Union workshop held in September, 2002 in Trieste, Italy. The workshop addressed the state of the science, gaps in our knowledge and methodologies related to several specific HAB issues of concern to the U.S. and to the EU, working toward a bilateral program on HABs. Assisted with drafting and editing of final report from this workshop – "The EU-US Scientific Initiative on Harmful Algal Blooms - A Report from a Workshop Jointly Funded by the European Commission - Environment and Sustainable Development Programme and the U.S. National Science Foundation".

- Attended the *International Seminars on Planetary Emergencies*, Erice, Italy and gave a presentation on "The Expanding Problems of Harmful Algal Blooms". A paper was also published on this subject (see Publications section for citation).

- Participated in the Sixth Session of the IOC Intergovernmental Panel on Harmful Algal Blooms, St. Petersburg, FL.

- Maintenance and updating of the internet listserver for ISSHA (The International Society for the Study of Harmful Algae).

National:

- Directing and organizing the *Second Symposium on Harmful Marine Algae in the U.S.* to be held December 9-13, 2003 in Woods Hole. This involves planning the scientific program; soliciting and compiling abstracts for oral presentations and posters; organizing discussion sessions; obtaining funding for travel awards for students and Postdocs, reviewing applications and making subsequent awards.

- Prepared white paper on harmful algal blooms for U.S. Commission on Ocean Policy report on Oceans and Human Health.

- Gave testimony before the Committee on Science, Subcommittee on Environment, Technology and Standards, U.S. House of Representatives Hearing on the "Harmful Algal Bloom and Hypoxia Research Amendments Act of 2003".

- Provided text and assisted with editing the *Proceedings of the ECOHAB/GLOBEC Gulf of Maine Modeling Workshop* held in June 2002.

- Distributed copies of *National Plan*, *ECOHAB*, *Economic Impacts* and other reports.

- Meetings and many presentations on national HAB issues at universities, meetings, workshops, and symposia. This involves considerable travel, preparation, and follow-up.

- Many discussions and meetings with federal agencies and others in Washington, DC to continue development and funding of the U.S. HAB program.

- World Wide Web homepage – www.redtide.whoi.edu/hab - continually expanding contents and updating information to include reports of HAB outbreaks, recent publications, funding opportunities, etc. This home page also generates numerous requests for additional information, photos, or references, which require personal attention.

- Participate in press briefings organized by Sea Grant and other organizations. Present HAB issues from National perspective.

- Responded to numerous newspaper and journalist inquiries. In order to ensure that HAB issues are presented correctly, and that they remain "visible" to the general public and to the federal officials, considerable time needs to be spent on interviews and other interactions with journalists.

- Maintenance of a central repository for pictures and videos that can be distributed to the public and the media.

Publications:

Anderson, D. M. 2003. The expanding global problem of harmful algal blooms. pp. 372-393, in: Ragaini, R. (ed.), International Seminar on Nuclear War and Planetary Emergencies, 27th Session, Erice, Italy, 18-26 August 2002. World Scientific Publishing Co., Pte. Ltd., Singapore.

NOAA Progress Report

SOLAS Summer School 2003

NOAA Grant: NA17RJ1223
July 1, 2002 to June 30, 2003

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Summary

This project provided travel support for eight United States students and one lecturer to Ajaccio, France to participate in the first SOLAS international summer school held from June 30 to July 11, 2003. The purpose of this school was to introduce graduate students and young researchers to different components of SOLAS research including biogeochemical interactions and feedbacks, exchange processes, and air-sea fluxes.

The overall goal of SOLAS is to understand biogeochemical and physical couplings between the surface ocean and the lower atmosphere and the associated influences on climate. While some air-sea exchange processes are well understood at the local level, they remain inaccurately quantified globally. For example, in spite of the fact that the partial pressure of CO_2 in water and the atmosphere is relatively well measured in the North Atlantic, the mean flux of CO_2 is known to less than 50% accuracy and its variability in inadequately known. For other processes, even the theoretical principles of local interactions remain uncertain. The generation of dimethylsulphide (a precursor of atmospheric sulphate aerosols and cloud condensation nuclei) is, for instance, linked to phytoplankton through unknown mechanisms. Building both on recent oceanographic and atmospheric research, SOLAS is a positive attempt at advancing the understanding of air-sea processes through interdisciplinary collaborations.

The SOLAS summer school used a theoretical framework, practical exercises, and laboratory experiments to promote an intensive learning environment. Most importantly, it provided the opportunity for young researchers interested in SOLAS science to meet one another and interact with lecturers currently researching these important global issues.

SOLAS summer school web pages (http://www.bgc.mpg.de/%7Ecorinne.lequere/solas/) describe the experience and are expected to include a sampling of lectures. These lectures covered such topics as the global carbon cycle, biogeochemical modeling, gas exchange, physical and biogeochemical processes in the coastal zone, data assimilation, and marine ecology. Practical workshops included a research cruise near Cargèse, laboratory experiments, computer modeling, meteorological observations, and instruction in oral and written communication skills. The experience culminated in student presentations on a variety of research topics, which are listed in the SOLAS web pages.

This proved to be a significant opportunity for students to enhance their knowledge with interdisciplinary instruction and form alliances capable of addressing the future challenges that face the field.

Publication on Gas Exchange Lesson Produced: First International SOLAS School: Air-Sea Gas Exchange Practical Workshop, edited by C. J. Zappa, B. Ward, D. T. Ho, R. Wanninkhof and W. R. McGillis, 2003.

NOAA Progress Report

Analysis of the 1999 Georges Bank Tidal Mixing Front Moored Array Data

NOAA Grant: NA17RJ1223
July 1, 2002 to June 30, 2003

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Over the past year, the primary focus has been to collect the various sources of data associated with the tidal mixing front mooring array and process them for analysis. In addition, James Lerczak (recently hired assistant scientist) and Robert Beardsley attended the Georges Bank Phase 4 Physical Oceanography Workshop in October, 2002, at the Woods Hole Oceanographic Institution. This allowed Lerczak, who is new to the Georges Bank study, to interact with the researchers involved in various aspects of the study, learn some of the major objectives of the study, and become acquainted with the various data sets collected during the field experiments.

The principle data sets processed for the tidal mixing front study included the current, temperature, and salinity measurements from the tidal mixing front array and from the southern flank mooring; meteorological data from the southern flank mooring and an NDBC buoy, and hydrographic data in the vicinity of the mooring array from cruises during the 1999 Georges Bank study. Processing involved putting all time series data onto a common time grid, running quality-control filters on the data, and storing all data in a common file format (MATLAB). Particular attention was paid to the acoustic Doppler current profiler (ADCP) data, which had spikes which were believed to be noise and not associated with real physical processes. These spikes were removed through a combination of a tidal harmonic analysis and hi-pass filtering. Processing is now complete.

In our analyses of the data sets, we will focus on two goals: 1.) formulate a description of the tidal mixing front, and the evolution of the front (density structure and currents) through the development of increased stratification from spring through summer (the duration of the mooring deployment); 2.) quantify the sub-tidal, cross-channel circulation in the vicinity of the front and the buoyancy flux across the front. In addition, we will collaborate with C. Chen (UMass-Dartmouth) to make detailed comparisons of the structure of the tidal mixing front circulation, stratification and fluxes revealed by this data set with that produced by the finite-volume numerical modeling of Chen.

NOAA Progress Report

Collaborative Research with PMEL: Exploring the Submarine Ring of Fire

NOAA Grant: NA17RJ1223
July 1, 2002 to June 30, 2003

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This document summarizes science results of the first year of the above referenced project between July 2002 through June 2003. This project is one part of a multi-investigator project entitled the Ring of Fire program led by Dr. Robert Embley of NOAA-PMEL Newport, OR. For our part of the science program, the autonomous underwater vehicle ABE (Autonomous Benthic Explorer) developed here at Woods Hole Oceanographic Institution (WHOI) was used to map the summit of Explorer Ridge (49°46'N 130°16'W) in the northeast Pacific off the west coast of Canada and United States (Figure 1). Located north of the more well-known Juan de Fuca Ridge, Southern Explorer Ridge (SER) is a medium-rate spreading center that is known to host a large hydrothermal vent complex known as "Magic Mountain". Previous dives by Canadian submersible Pisces IV in the 1980's and ROV ROPOS in the 1990's documented the existence of the active "Magic Mountain" vent area and many areas of extinct sulfide chimneys within the rift valley. Magic Mountain was classed then as one of the largest sulfide structures known on the modern seafloor [*Tunnicliffe et al., 1986; Scott et al., 1990*] and yet it has not been revisited for some time and has not been imaged with modern and state of the art mapping systems available today.

The Mapping Program and the Autonomous Benthic Explorer (ABE)

The mapping program was conducted during a cruise of the research vessel Thomas Thompson that left Seattle on June 28th and returned to Victoria, British Columbia Canada, July 11th. Dr. Robert Embley was chief scientist on the leg. For the high-resolution mapping we utilized the autonomous underwater vehicle ABE (Figure 2). ABE is a fully autonomous underwater vehicle that navigates itself around an acoustic transponder net previously deployed on the seafloor. ABE drives along on a preplanned dive track and is fully autonomous in that it makes its own decisions in avoiding the seafloor, maintaining its altitude and depth and understanding where it is in the world. ABE carries a number of mapping systems including a mechanically scanned 675 khz pencil-beam sonar (Imagenex), a CTD, optical backscatter, redox potential and a 3 axis fluxgate magnetometer. For this particular project ABE was also equipped with a 200 khz multibeam sonar system, the Simrad SM2000. This latter sensor system provided an order of magnitude improvement in the density of coverage seafloor depth estimates (i.e. pings), which translates into a much finer resolution bathymetric map than previously had been possible.

ABE completed 7 full dives, averaging approx. 18 hours bottom mapping time per dive and mapped an area approx. 7 by 3.5 km along the summit of Southern Explorer Ridge (Figure 3 and 4). Other science programs during the cruise included collecting EM300 ship-based swath bathymetry data over a large area of Explorer Ridge and CTD tow-yos to locate any active hydrothermal activity. The overall goal of the cruise leg and this project was to identify and locate hydrothermal activity on this part of the midocean ridge system and to "rediscover" the Magic Mountain vent field in order to establish its relationship to other vents systems now known to exist further south along the Juan de Fuca Ridge. The specific science goal of this project was to collect high-resolution bathymetric data along with magnetic field data in order to define the hydrothermal systems present at the summit of Explorer Ridge.

High Resolution Magnetic Mapping

The magnetic properties of ocean crust are sensitive to the alteration and thermal environments associated with hydrothermal vent systems [*Ade-Hall et al*., 1971; *Johnson and Pariso*, 1987; *Watkins and Paster*, 1971]. Hydrothermal alteration can rapidly destroy the magnetic minerals within the extrusive crust, creating non-magnetic pipe-like upflow zones beneath focused vent sites and demagnetized zones along fluid pathways, such as faults and subsurface permeability zones [e.g. *Tivey and Johnson, 2002; Tivey et al.,1993; 2003*]. Likewise, the elevated temperatures beneath vent fields can lead to thermal demagnetization of the magnetic minerals. Thermal demagnetization is potentially a more dynamic response, if for example, vent temperatures change systematically over time. While magnetic studies are inherently non-unique, systematic patterns in the magnetization contrast can provide important insight into the degree of homogeneity or heterogeneity of the subsurface crust. The magnetic measurements can also be collected on a spatial scale that is relevant to the process of fluid flow through the crust ranging from the individual vent chimneys on a scale of meters to the rift valley scale of several hundreds of meters. Magnetic mapping was therefore undertaken at SER to assist in delineating areas of crustal hydrothermal alteration. Previous high resolution magnetic field mapping over the Endeavour Ridge segment of the Juan de Fuca Ridge, just to the south of SER, revealed the presence of tightly constrained magnetization lows (typically 100 m diameter) that correlated spatially with areas of both active and inactive hydrothermal activity [Tivey and Johnson, 2002].

The new magnetic field mapping at SER shows similar relationships, although with some important differences (Figure 5). Magnetization lows are primarily concentrated in the rift valley with a few lows off-axis associated with major faults. The lows appear to be more elongate along the rift valley and broader in plan view (several 100's of meters) compared to Endeavour. Previous SER mapping found extensive hydrothermal deposits along the rift valley although most were relict deposits. Thus, it appears that hydrothermal activity in the rift valley has been extensive, which has influenced the magnetization pattern. Unlike Endeavour Ridge, the active Magic Mountain venting site was found "outside" of the rift valley, adjacent to the east valley wall (Figure 6). This suggests fluid pathways exist through the uplifted wall of the rift valley. The active venting Magic Mountain area and rift valley wall has reduced magnetization, although not as strongly defined as the active vent sites at Endeavour. This suggests that either Magic Mountain is too young to have formed an alteration halo, although ROV ROPOS observations suggest that the vent system is relatively mature, or that the fluid flow and alteration is simply more broadly distributed along the wall. Many relict hydrothermal chimneys were found in the area of the Magic Mountain site suggesting a broad area of upflow and thus the latter hypothesis is preferred.

In addition to magnetization lows, areas of strong magnetization appear to correlate with the many volcanic constructional features seen in this area of Explorer Ridge. This presumably implies greater volume of magnetic material rather than enhanced magnetization, although further work needs to be done to investigate these correlations. These volcanic domes dominate the morphology of the rift axis, but they are also heavily dissected by pervasive faulting (Figure 4). Further work needs to be done to investigate the relationships between the magnetization highs and lows with various seafloor morphological features mapped on the seafloor.

Publications resulting from this project

Tivey, M.A., D. Fornari, H. Schouten, A. Bradley, D. Yoerger, H.P. Johnson, R. Embley, W. Chadwick, T. Shank, S. Hammond, High-resolution magnetic field and bathymetric imaging using autonomous underwater vehicles, remotely operated vehicles and submersibles, EGS-AGU-EUG Spring Meeting, 5, 2858, Abstract EAE03-A02858, Nice, France, May 2003.

Tivey, M.A., R. Embley, W. Chadwick, A. Bradley and D. Yoerger, High-Resolution Magnetic Field Mapping Over Explorer Ridge - NOAA Ocean Exploration Program, EOS Trans. AGU, 83 (47), T11C-1267 (Fall Meeting) 2002.

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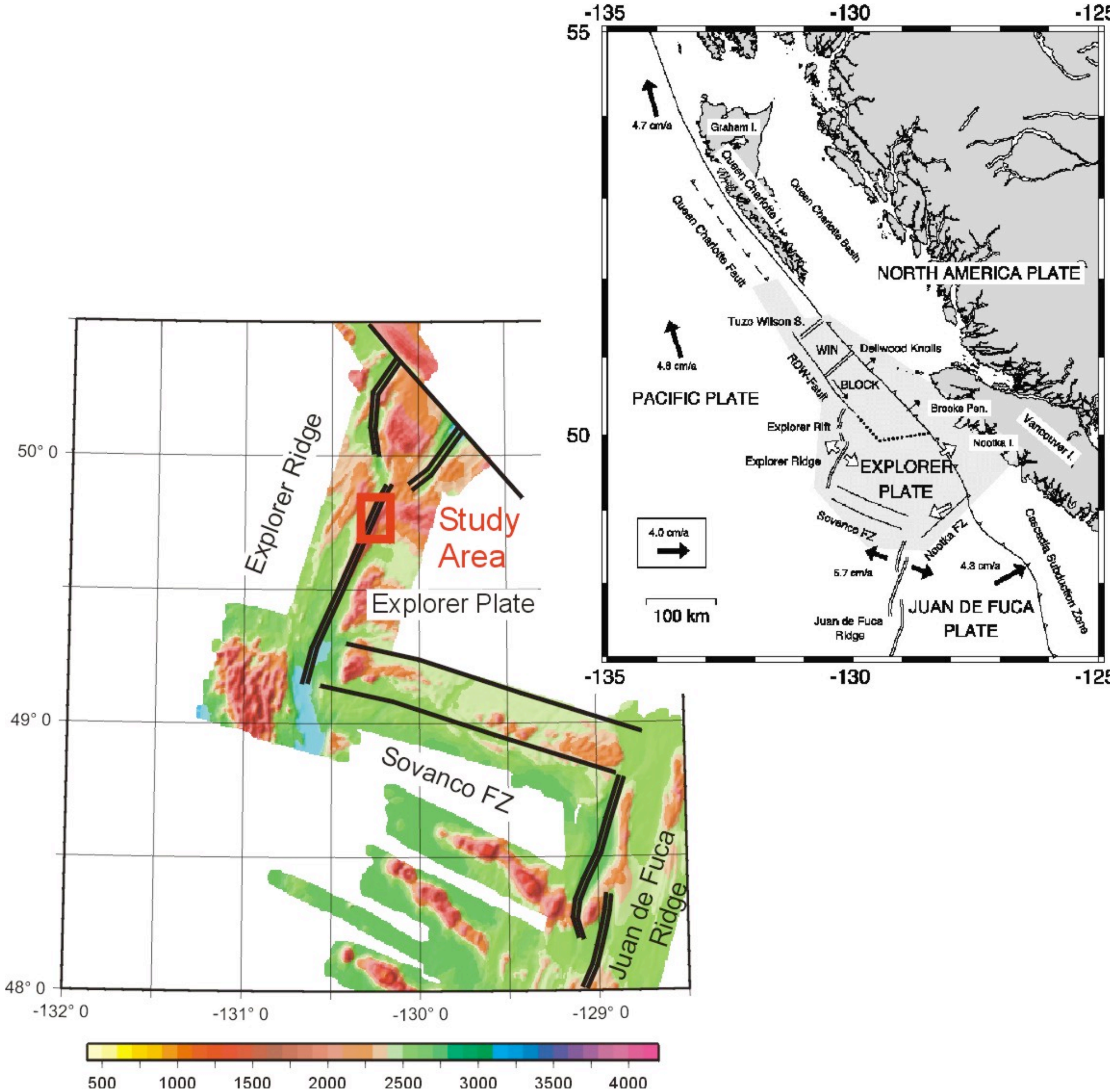

Figure 1. Sea Beam bathymetry map of Explorer Ridge showing the midocean ridge spreading center geometry just north of the Sovanco Fracture Zone and the Juan de Fuca Ridge. Study area is shown by the red box. Inset map shows the tectonic plates and spreading centers of the northeast Pacific showing the location of Explorer Ridge spreading center just north of the Juan de Fuca Ridge spreading center. The southern end of Explorer Ridge is defined by the Sovanco Fracture Zone. The northern end is defined by the Revere-Dellwood-Wilson Fracture Zone (RDW) which offsets Explorer Ridge from the small spreading segments of the Dellwood Knolls and Tuzo Wilson Seamount spreading centers. Map adapted from Braunmiller and Nabelek (2002).

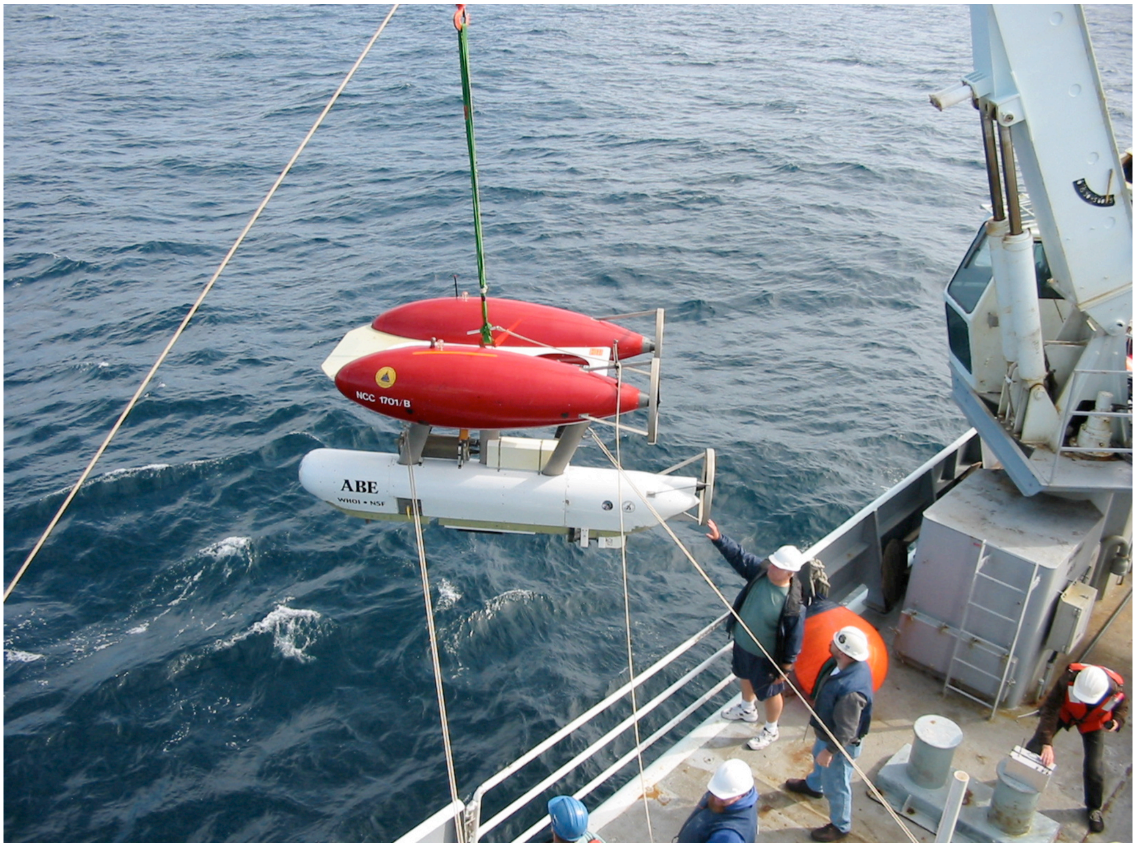

Figure 2. The Autonomous Benthic Explorer, ABE shown during a launch. The red fiberglass housings contain flotation, acoustic transponders for navigation and two forward/reverse thrust motors. The white pressure housing contains the electronics that controls ABE's operation and a third forward/reverse thrust motor. The buoyancy of ABE is such that it can hover over a single location if so desired.

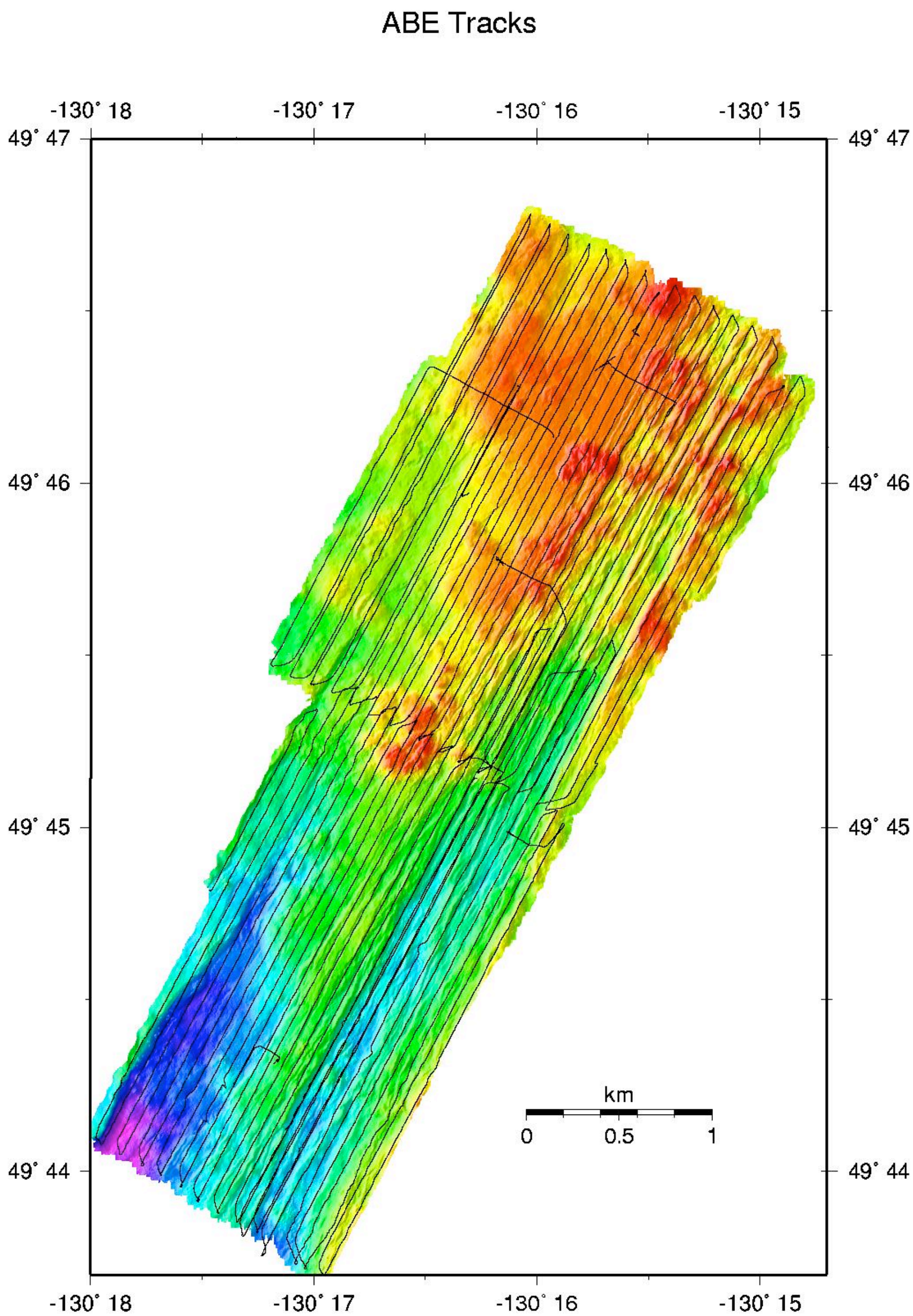

Figure 3. ABE tracklines plotted on the ABE collected Imagenex bathymetry map. This plot is a composite of 7 ABE dives, each lasting approximately 18 hours each). Tracks were flown at a nominal line-spacing of 40-60 m and an altitude of 60 m.

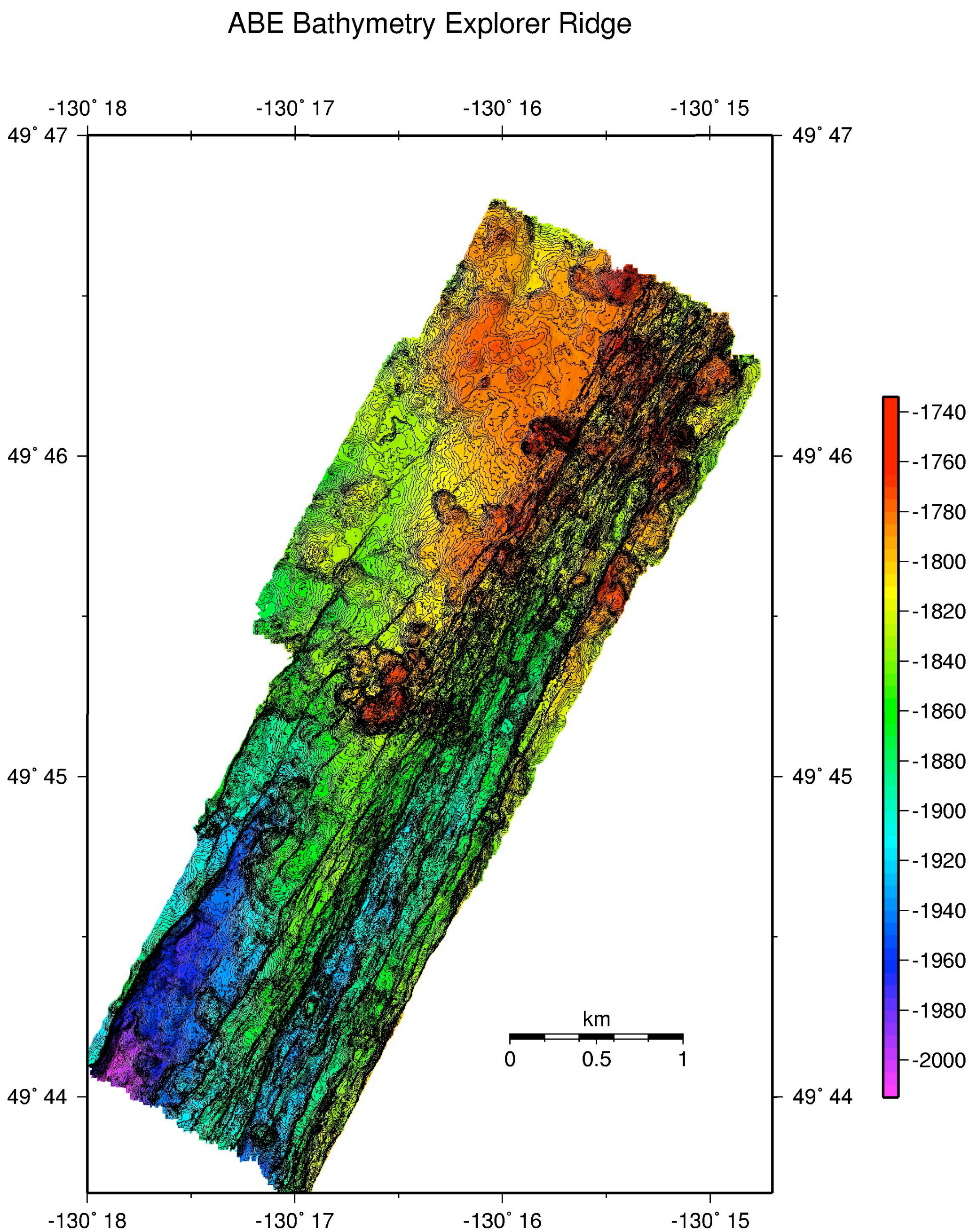

Figure 4. ABE Imagenex bathymetry map with 2 meter contours. Notice the highly lineated terrain indicative of faulting that marks to spreading axis. Superimposed on this tectonic fabric are constructional volcanic features (volcanos) that indicate a highly focused and localized delivery system of magmatic material to the seafloor.

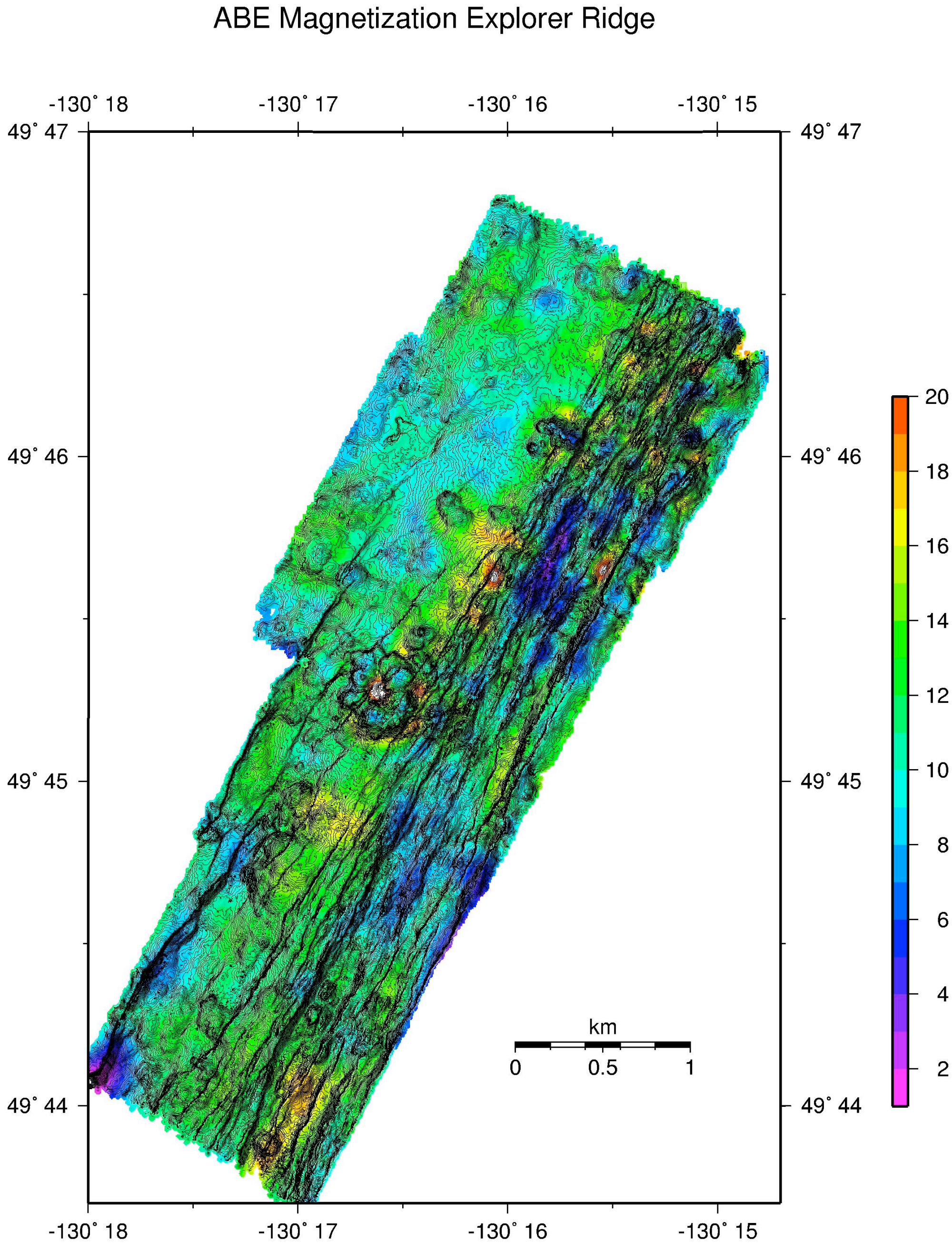

Figure 5. Crustal magnetization map computed from the observed magnetic field assuming a constant thickness source layer thickness of 500 meters and whose upper surface is bounded by the bathymetry (Figure 4). Bathymetry contours (2 m interval) have been superimposed on the colored magnetization intensity. The magnetization level has been shifted by adding sufficient annihilator to make all the crust positively magnetized because the area of the survey is well within the normal polarity Brunhes chron. The annihilator is magnetization function (in this case based on the bathymetry) that produces no magnetic field; thus an infinite amount of annihilator could be added to the solution. Typically, however, the annihilator results in a DC shift in the magnetization solution.

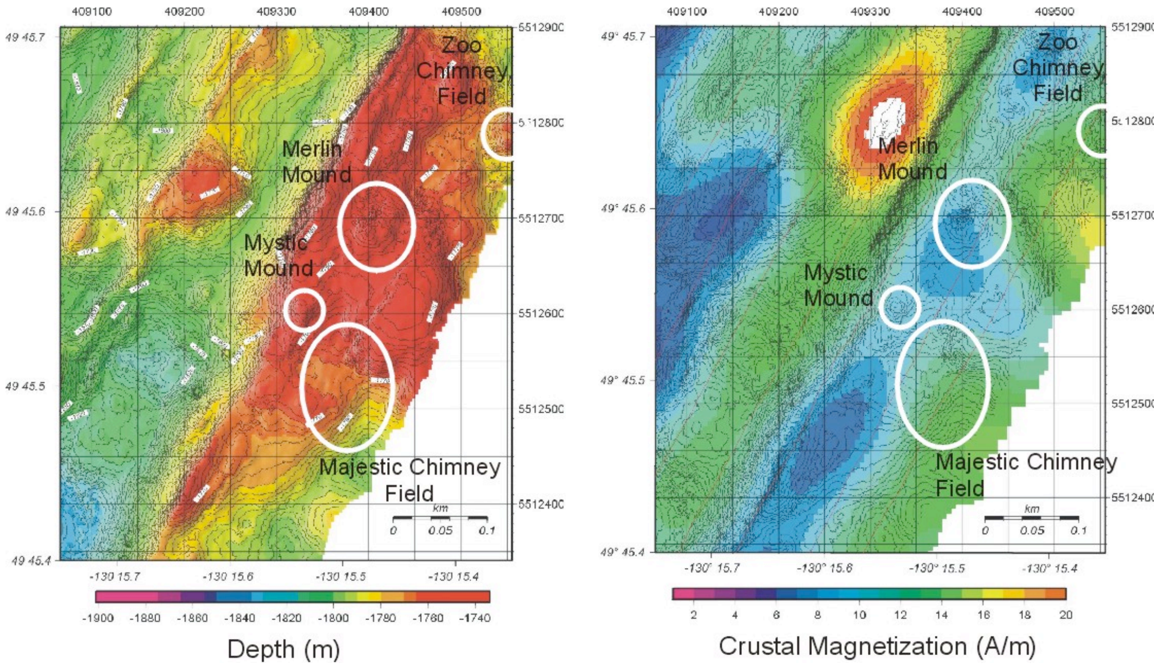

Figure 6. Left figure shows ABE Imagenex bathymetry over the Magic Mountain hydrothermal area. Subsequent dives by ROV ROPOS identified several hydrothermal mounds venting fluids up 311 deg C. Right figure shows the crustal magnetization of the Magic Mountain area showing relatively low magnetization corresponding to the active vent sites possibly related to age.. The Majestic field has the youngest hydrothermal chimneys growing directly out of basalt, while the Mystic and Merlin mounds appear to more mature areas.

NOAA Progress Report

Patterns of Energy Flow and Utilization on Georges Bank

NOAA Grant: NA17RJ1223
July 1, 2002 to June 30, 2003

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Accomplishments
Linear network analysis: This work has focused on the lower trophic levels (the microbial loop. See Fogarty and Stockhausen for upper level analysis)
Previous methods (ECOPATH and "inverse" techniques) appear inadequate for these components – especially in relation to ecologically acceptable optimization criteria. We have developed an alternative approach and are carrying out comparisons with forward and inverse programs. These will form the basis for applications in year two.

Non-linear modeling: some work has been started on this and used in;
a paper on Marine Protected Areas (Steele and Beet; published)
a review of Stability and Diversity in Coastal Ecosystems (Steele and Collie, submitted)

<u>Papers</u> (acknowledging this funding)

Steele and Beet (2003) Proc. Roy. Soc (Suppl) Available as PDF file

<u>Talks</u> ; JHS (2002-3)

Nov.: Effects of trawling on the seabed (Tampa: Amer. Fish. Soc)
March: Resilience of marine pelagic systems (Zurich: 5th Int. Conf. on Env. Future)
April: Regime shifts: reconciling theory and observation (Villefranche: Int. Ocean. Comm.)
May: Are fisheries sustainable? (Thessalonika: E.U. meeting on E. Mediterranean ecosystems)

NOAA Progress Report

GLOBEC Data Synthesis: "GLOBEC-01: Phase IV Support for the Scientific Investigators" Data Synthesis Symposia

NOAA Grant: NA17RJ1223
July 1, 2002 to June 30, 2003

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This project supports the US GLOBEC Georges Bank Phase IV yearly workshops and the symposia. These funds are used to defray the costs of the meeting facilities and pay partial or full travel support for those investigators whose presence at one or more of these meetings is deemed important by the US GLOBEC Georges Bank Executive Committee and yet may not have sufficient funds to attend the meetings on their own. The funds are also used to assist in the documentation of the symposia through the preparation of reports, which will be published both in hard copy and on the Program's web site (http://globec.whoi.edu/), as has been done in the past. During the fourth year of the project, funds will be used to assist in the planning and development of the book showing the results of the analysis and synthesis of the GLOBEC George Bank program data sets and modeling efforts.

There are five US GLOBEC Georges Bank projects in the Phase IV program. These are as follows:

The Physical Oceanography of Georges Bank and Its Impact on Biology
Robert Beardsley (WHOI), Ken Brink (WHOI), Dick Limeburner (WHOI), Jim Churchill (WHOI), Jim Ledwell (WHOI), Changsheng Chen (UMassD), James J. Bisagni (UMassD), Charles Flagg (BNL), Peter Smith (BIO), Ron Schlitz (NEFSC), Jim Lerczak (WHOI)

Zooplankton Population Dynamics on Georges Bank: Model and Data Synthesis
Peter Franks (SIO), James Pringle (UNH), Changsheng Chen (UMassD), Ted Durbin (URI), Wendy Gentleman (UW)

Patterns of Energy Flow and Utilization on Georges Bank
Dian Gifford (URI), James J. Bisagni (UMassD), J.S. Collie (URI), E.G. Durbin (URI), Michael Fogarty (NEFSC), Jason Link (NMFS), Larry Madin (WHOI), David Mountain (NMFS), Debbie Palka (NMFS), Michael E. Sieracki (BLOS), John Steele (WHOI), B.K. Sullivan (URI)

Tidal Front Mixing and Exchange on Georges Bank: Controls on the Production of Phytoplankton, Zooplankton and Larval Fishes
Robert W. Houghton (LDEO), Dave Townsend (UME), Changsheng Chen (UMassD), R. Gregory Lough (NEFSC), Lew Incze (BLOS), Jeff Runge (UNH)

Integration and Synthesis of Georges Bank Broad-Scale Survey Results
Peter Wiebe (WHOI), Carin Ashjian (WHOI), Larry Madin (WHOI), Dennis McGillicuddy (WHOI), Dave Mountain (NMFS), J.R. Green (NMFS), Peter Berrien (NMFS), S.M. Bollens (SFSU), Dave Townsend (UMaine), Ted Durbin (URI), Bob Campbell (URI), Barbara Sullivan (URI), Ann Bucklin (UNH), Jeff Runge (UNH).

The PIs in the projects listed above participated in a number of workshops or working group meetings during the year, some of which were supported by this project. The first occurred in July 2002 and the results of that meeting are summarized in the "Report of the U.S. GLOBEC Georges Bank Phase IV Synthesis - Startup Planning Meeting 11-12 July 2002, Woods Hole, MA".
(See http://globec.whoi.edu/globec-dir/phase4doc/july2002/report.shtml) This meeting was attended by nearly all of the PIs involved in the five phase IV synthesis projects. The goals of the meeting were:
To exchange information about the nature of each of the projects, including discussion about the context and conceptual framework for the synthesis effort as well as pertinent details.
To discuss where input and results from other groups were needed, where opportunities for collaborations existed, and what elements might be missing that could hamper the synthesis effort.
To develop a time line for working group meetings, symposia, meeting presentations, and publications.

The second meeting was held on 29 October - 1 November 2002. This meeting was a combined, back-to-back meeting of members in the Physical Oceanography project, Tidal Front Mixing project and the Broad-Scale project. Investigators from the three projects attended most of the groups' sessions. One outcome of the broad-scale meeting was the tentative agreement of a grid of station positions to which biological and physical data would be used to "objectively map" the broad-scale data to create a master set of biological and physical data in a uniform framework. A working group was established to fine-tune the stations and it met in December 2002 to finalize the station grid. The broad-scale station grid working group's report is also available on-line at http://globec.whoi.edu/globec-dir/phase4doc/grid/grid_report.html. This project supported the meetings of the U.S. GLOBEC Executive Committee (EXCO) during the past year. It also provided some support for junior scientists to attend the ICES/PICES/GLOBEC sponsored Symposium on Zooplankton Ecology titled "The Role of Zooplankton in Global Ecosystem Dynamics: Comparative studies from World Oceans", which took place in Gijon, Spain between 21-23 May 2002.

Planning is complete for the first US GLOBEC North Atlantic Georges Bank Program Science PI Meeting since synthesis work has commenced. The meeting will be held 18 - 20 November 2003 at the Whispering Pines Conference Center, Alton Jones Campus facility. This three-day meeting will bring together the US GLOBEC Georges Bank Phase IV science investigators and other investigators to review our current research progress and continue our efforts to synthesize and analyze our results to date. On-line registration for this meeting has already begun. The November meeting will provide an opportunity to work on the presentations for the Ocean Science meeting in January 26-30, 2004 in Portland, Oregon, which has a special session designed for GLOBEC PIs titled “Understanding the Physical and Biological Coupling of Marine Population Dynamics”.

NOAA Progress Report

U.S. GLOBEC: Integration and Synthesis of Georges Bank Broad Scale Survey Results

NOAA Grant: NA17RJ1223
July 1, 2002 to June 30, 2003

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Program Manager: Dr. Beth Turner,
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National Oceanographic and Atmospheric Administration
Coastal Ocean Program

Summary

This project is a collaboration between fourteen investigators from five universities and one federal laboratory. The funding for this project has been split between NOAA via NMFS, NOAA via CICOR, and NSF. Funds for the CICOR portion of the project were received in September 2002 and the funds from NSF were received in March 2003. The mismatch in arrival of the funding prevented some investigators from spending much

time on the project to date. This report is a summary of what the investigators as a group have accomplished this past year.

The principal objective of this project is to utilize the very comprehensive U.S. GLOBEC broad-scale data sets that now exist to address two overarching questions:

1) What controls inter-annual variability in the abundance of the target species (cod and haddock larvae, Calanus finmarchicus, and Pseudocalanus spp) on Georges Bank (e.g., bottom up or top down biological processes, or physical advective processes)?
2) How are these processes likely to be influenced by climate variability?

The project involves work in two coordinated efforts.

1) Data completion and data management
2) Data analysis, integration, and interpretation
A. Hydrographic-biological Relationships
B. Integration of Rate Processes and Broad-Scale-Distribution Data Sets
C. Building climatology using objective mapping or kriging
D. Modeling

The focus in the first year has been on integrating the broad scale data sets within themselves. The project PIs participated in two workshops to coordinated data analyses and inter-comparisons. The first occurred in July 2002 and the results of that meeting are summarized in the “Report of the U.S. GLOBEC Georges Bank Phase IV Synthesis Startup Planning Meeting 11 12 July 2002, Woods Hole, MA”. This meeting was attended by nearly all of the PIs involved in the five phase IV synthesis projects. A second meeting was held of the PIs associated in this project in November 2002. This meeting was held back to back with a meeting of the Physical Oceanography group and investigators from both projects attended most of both group’s sessions. One outcome of the November meeting was the tentative agreement of a grid of station positions to which biological and physical data would be used to “objectively map” the broad-scale data to create a master set of biological and physical data in a uniform framework. A working group was established to fine-tune the stations and it met in January 2003 to finalize the station grid. This station grid has been circulated to all of the project PIs for use in their data mapping efforts and is posted on the GLOBEC database as the “broadscale grid” (http://globec.whoi.edu/jg/dir/globec/gb/).

A number of the PIs in the project participated in the ICES/PICES/GLOBEC sponsored Symposium on Zooplankton Ecology titled "The Role of Zooplankton in Global Ecosystem Dynamics: Comparative studies from World Oceans", which took place in Gijon, Spain between 21 23 May 2002.

Summary of work to date

The following is a summary of the work that has been completed over the past year.

Broad-scale egg samples for both cod and haddock have been processed to consider possible maternal influence on egg viability by D. Mountain and colleagues. Since increased egg size may reflect better condition and overall viability, the diameters of 50 eggs for each species were measured for each year. No indication was found that interannual variation in egg calculated mortality rates was related to variation in egg size. Several papers have been submitted for publication and a paper has been submitted for presentation at the ICES Annual Meeting in Tallinn, Estonia later this month (September).

The Durbin group oversaw the collection and processing of the zooplankton samples collected on the broad-scale cruises. Both a 1 m2 MOCNESS and a zooplankton pump were used during the surveys. The MOCNESS was equipped with 0.15 mm mesh nets and was used at all standard stations. Depths sampled were 0-15 m, 15-40 m, 40-100 m or bottom, and 100-bottom. The zooplankton pump was used at about half the stations. Samples were filtered through a 0.05 mm mesh net during 1995 and a 0.035 mm mesh net from January 1996 on. Samples were collected at the same depth ranges as the MOCNESS down to approximately 100 m or the bottom if less than 100 m. There was a need to compare the results from the two different sampling systems. As a result, Durbin and colleagues have carried out a comparison of data for the two sampling systems to determine which is the appropriate source of data for subsequent analysis. Abundances were vertically integrated across the sampling depths chosen for analysis and expressed as numbers per m2 of sea surface. For the comparison of sampling systems, depth ranges were chosen so that the bottom of each MOCNESS and pump depth profile were within 10 m of each other. Data were grouped into periods when the centrifugal pump (February 1995 through May 1998) and the diaphragm pump (June 1998 through June 1999) were used. At each station a selectivity index was calculated:

I = (MOC - Pump)/(MOC + Pump)

Where MOC and Pump are the numbers/m2 for each station. The Index has values from +1 to -1. Indices were compared with total width for adult females and males and individual copepodid stages of Calanus finmarchicus and Pseudocalanus, and adult females and males of Centropages typicus, C. hamatus, Metridia lucens, Oithona spp (primarily Oithona similis) and Temora longicornis, and adults of Microcalanus pusillis. Since copepodid stages were grouped (C1-C5) for these latter taxa no meaningful estimation of size could be made and no comparison was made. However, indices were calculated for each of these taxa. Only stations were taxa were collected by both sampling methods were used.

This analysis by the Durbin Group indicates that C1 and C2 of Calanus and all C1-C5 of Pseudocalanus were under sampled by the MOCNESS relative to the pump. Comparison with the width of these stages indicates that extrusion should not be a problem for most because their widths are greater than the 0.15 mm mesh used. Comparison of catch curves of Calanus for the pump and MOCNESS suggests that the MOCNESS is under sampling by an average of 37%, perhaps because of overestimation of the volume filtered relative to the actual volume filtered. The results of this analysis will be very important in standardizing the zooplankton counts for the broad-scale inter-comparison studies through preparation of maps of zooplankton taxa on Georges Bank, which are now taking place. For each taxon, these include 5-year mean abundance for each month, the abundance for each month, and the deviation during each month from the five year mean. These maps will be placed on the Durbin GLOBEC website and linked to the U.S. GLOBEC server (http://globec.whoi.edu). Some preliminary results were presented at the zooplankton production symposium in Gijon. Some of the data have been provided to a number of investigators including Dennis McGillicuddy, Changshen Chen, and Wendy Gentleman.

Work being carried out by J. Runge and colleagues is proceeding toward the synthesis of reproductive rates and mortality rates of target zooplankton species. The reproductive rates of C. finmarchicus at broad-scale stations have been calculated for all broad-scale cruises. In collaboration with E. Durbin, B. Niehoff, S. Plourde and M. Ohman, relationships of egg production of Pseudocalanus spp. using measurements of prosome length and chlorophyll a concentrations have been calculated, for use in estimating egg production rates of these target species at the broad-scale stations. Two research articles have been submitted for publication. Niehoff and Runge (accepted) describes a modification of the procedure for estimating C. finmarchicus egg production rates from the preserved broad-scale samples. This modification explicitly accounts for food limitation effects on clutch size. Ohman et al. (submitted) uses Georges Bank broad-scale data in a comparative study of mortality patterns of C. finmarchicus across the North Atlantic.

Broad-scale biovolume analyses and comparison to bioacoustic data collected and the synthesis of the Gulf of Maine net tow and acoustics data collected during 1997,1998, and 1999 are being conducted by the Wiebe and colleagues. The work on this project has coincided with work on a closely related project involving the processes controlling the recruitment of Calanus finmarchicus populations in the Gulf of Maine. The last cruises on this project also took place in 1999 and the work up of the samples and the analyses of the data have been going on in parallel. Some of this work has been carried out with Karen Fisher (who completed her Ph.D. thesis while working on the broad-scale project). The kriging technique and a newly developed wavelet/fractal interpolation scheme has been applied to the acoustic data sets obtained on the broad-scale cruises. These data will enable seasonal and the year to year variations in acoustic backscattering and the environmental data that were collected on Georges Bank surveys to be compared. The broad-scale zooplankton biovolume data collected with the Bongo nets by J. Greene will be compared with the acoustic data. In addition as described below, the Gulf of Maine acoustics data will be compared with those collected on Georges Bank.

A series of cruises lead by C. Greene were conducted in the autumns of 1997, 1998, and 1999 to survey diapausing populations of Calanus finmarchicus and their predators in Wilkinson, Jordan, and Georges Basins (Gulf of Maine) as part of the U.S. GLOBEC Georges Bank program. The sampling was done with the BIO-Optical Multi-frequency Acoustical and Physical Environmental Recorder or BIOMAPER-II, a towed system consisting of a multi-frequency sonar, a Video Plankton Recorder (VPR), a bio-optical sensor package, and an environmental sensor package (CTD). It was towyoed along survey track-lines in each of the basins to collect acoustic data, video images, and environmental data between the surface and bottom. In addition, a 1-m2 MOCNESS was towed obliquely from near-bottom to the surface at stations in each basin, sampling eight depth intervals for biomass, taxonomic analyses, and species counts. During the three years, a dramatic change in the hydrography took place in the Gulf of Maine that lagged by about two years after the precipitous drop in the NAO index that occurred in 1996. Colder and fresher water of Labrador Sea origin was present throughout much of 1998. Coincidently, the autumn diapausing C. finmarchicus abundance was much lower and there were also extraordinary numbers of a large predatory siphonophore. Despite the lower Calanus abundance in 1998, overall zooplankton biomass levels were comparable among the three years. This comprehensive data set may enable the issue of far-field (principally NAO driven changes in hydrography) and near-field effects (predator/prey relationships) on the plankton community in the Gulf of Maine basins to be evaluated. A report of this work will be presented at the ICES Annual Science Conference in Tallinn, Estonia later this month.

An adjoint data assimilation approach has been used by D. McGillicuddy and X. Li to explore the physical and biological controls on Calanus finmarchicus C2 to C5 copepodites in the Georges Bank region. Monthly climatological distributions of Calanus finmarchicus from the GLOBEC Georges Bank Broad-Scale Surveys were assimilated into a coupled physical-biological model. The model was run over the observational period between January and June. The inversion quantifies the supply stock of the Calanus finmarchicus copepodites to Georges Bank, the biological sources/sinks, and physical advective/diffusive transports of these animals near the Georges Bank region. Results show that the Wilkinson Basin and the Georges Basin provide important sources of C4 and C5 in spring and summer. Sources from these deep basins and the Northwest North Atlantic Slope Water become larger in spring and summer. Both biological reaction and physical advection are important for the observed distributions. During spring and early summer, biological production is the dominant factor responsible for the high abundance of Calanus finmarchicus on the Bank. The northwest portion of the Crest, the Northeast Peak, and the Southern Flank are hot spots of high productivity on the Bank. The new generation is then advected along the Bank by the recirculation. These animals are washed away from the Bank via the Northeast Peak and the Southern Flank during May - June. The inferred convergence of advective flux shows a robust pathway delivering the copepodites away from the Wilkinson Basin, via the Great South Channel, to the northwest Crest and the southern tip of the Great South Channel between February and June. During the period when Calanus finmarchicus is abundant on Georges Bank, this species is transported to the Browns Bank, the Georges Basin, the Nantucket shoals, and the Slope Water away from the Bank edge, by turbulent mixing.

In a related effort, A. Bucklin and D. McGillicuddy have focused on the Bank-wide patterns of distribution and abundance of two species of Pseudocalanus, P. moultoni and P. newmani. The objectives include: 1) integrative data analysis, to compare patterns among all target species and any other taxa that are abundant and/or ecologically important; 2) application of numerical, coupled biological / physical models to the Pseudocalanus spp. distributional data to infer processes from the patterns; and 3) synthesis of the patterns and processes of all species to examine the role of each species in the Georges Bank ecosystem.

The work is on schedule with the first goal being data completion. After determining that the earlier mapping and modeling studies (see Bucklin et al., 2001; McGillicuddy and Bucklin, 2002) excluded a sizable fraction of the copepod population concentrated in the deepest strata of the water column, another 50+ samples using the species-specific PCR (SS-PCR) assay to discriminate the two species of Pseudocalanus from the 1999 Broad-Scale Survey data set have been analyzed. In addition, 20 samples from NOAA/NEFSC Ecosystem Monitoring Surveys during 2001 – 2003 have also been analyzed in order to expand our analyses into the Gulf of Maine.

The analysis of 1999 Broad-Scale Surveys is nearing completion, as well as the cross-frontal process cruise during June 1999 (U.S. GLOBEC PI Karen Wishner, URI). These data will be objectively mapped by D.J. McGillicuddy, and used for adjoint modeling of the dynamics of maintenance of the species on the Bank. These results have been presented previously in several meetings; a technical report and presentation for the ICES Annual Science Conference are in preparation.

Integration and synthesis of the nutrients and chlorophyll data are being carried out by D. Townsend in collaboration with Maura Thomas. Ongoing effort involves re plotting and re contouring the data sets on phytoplankton chlorophyll and nutrient distributions on Georges Bank. Preliminary budgets are now being constructed, which include some of the organic nitrogen and carbon measures. Because funding was received a relatively short time ago, much work remains to be done. There is strong impetus to fully participate in the data assimilation process with the other GLOBEC colleagues involved in synthesis and this work will proceed toward this end.

Since funds became available in early 2003, the SFSU portion of the predation group lead by S. Bollens has been focusing efforts on organizing the 10-m2 MOCNESS data into an access database and undertaking basic data reduction and manipulation to display the distribution and abundances of the major macrozooplankton and micronekton predators. The relationship between these biota and various environmental conditions are being examined, especially hydrography and Slope Water intrusions. This work has resulted in two manuscripts (Stoltz et al., in revision and Brown et al., in revision). Also begun are various multivariate analyses to examine overall community structure within the Georges Bank macrozooplankton and micronekton. The results of this work may be submitted as an abstract to the GLOBEC special session at AGU in Portland, OR in January 2004. Finally, the integration of the distribution and abundance data described above with various rate process data derived from GLOBEC process cruises and the literature will eventually allow the predation group (Madin, Bollens, Sullivan, et al.) to generate broad-scale distributions of specific predation mortality rates for each target (prey) taxon.

Future Work:

In the immediate future, the project PIs need to prepare titles and abstracts for a special session at the AGU Ocean Science Conference designed to attract contributions from the U.S. GLOBEC program participants. This meeting will take place in Portland, Oregon in January 2004. There is also a Phase IV PI meeting scheduled for November 2003, which will enable the investigators to present the first results of the synthesis effort and to plan the next steps for data integration and publishing of the results.

Papers submitted or published:

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Durbin, E.G., R. Campbell, M. Casas, B. Niehoff, J. Runge, M. Wagner. 2003. Interannual Variation in Phytoplankton blooms and Zooplankton Productivity and Abundance in the Gulf of Maine During Winter. Mar Ecol Progr Ser. 254:81-100.

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Manning, C.A. and A. Bucklin (2003) Multivariate analysis of temporal and spatial patterns of planktonic copepod abundances in the western Gulf of Maine. (14-19 Februrary 2003) ASLO Aquatic Sciences Meeting, Salt Lake City, Utah.

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NOAA Progress Report

Variations in Oceanic CO2 Concentration, Transport and Divergence in the Atlantic

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NOTE: This project is funded 50% through NOAA/CICOR and 50% through NSF

1. A Comparison of the actual accomplishments compared to the objectives **established for the period. In this first year of the project we are:**

a) Assembling the data, and reformatting them for use within the local data archives.

We have retrieved the WOCE Atlantic one-time hydrographic lines from WHPO. R. Key at Princeton has sent us the GLODAP data set containing carbon parameters where available for these Atlantic sections. This data set also includes estimates of anthropogenic carbon (K. Lee pers. comm.) which has also been reformatted into our data structures. Hydrography and anthropogenic carbon estimates for the AR7W line across the Labrador Sea have been obtained from K. Azetsu-Scott and are part of our initial model.

b) Assembling the wind fields for use within the model.

We are using NCEP Reanalysis winds to compute initial estimates of Ekman transport across the sections and we are using the range of estimates provided by NCEP, Trenberth, SSMI, Hellerman and Rosenstein, ERS, Oberhuber and SOC products to compute an estimate of the uncertainty in the Ekman transport which is also used as an input to the model. We have retrieved these data sets and have the necessary software for using them in our system.

c) Selecting layer definitions and reasonable initial reference levels based on property distributions and literature.

We have chosen 21 neutral density layers to describe the Atlantic.

d) Creating an initial two box model using the 1998 24N A5 transect, the 1997 47N A2 transect, the 1997 AR7W line and one section between the Hebrides and Greenland from the 1997 A24 line. This model is nearly ready for inversion with two different runs, one using initial surfaces of zero motion and one using the statistics from float data at 700 dbar compiled by Lavender et al (2002) as the initial velocity estimate across the two northern transects. A poster as presented on this model setup (see below under publications). This initial model was initially set as a second year step.

e) Through our subcontract to the University of Miami, Dennis Hansell has made good process analyzing the available North Atlantic DOC data. We have a manuscript in preparation describing how through the use of the 1998 24N Atlantic DOC data and the transport results of our inverse model along this line a direct estimate of metabolic state of the North Atlantic Basin can be made. We expect to submit this mansuscript within the next few weeks.

Hansell. D. A., Ducklow H. W., Macdonald, A. M. and M. O'Neil Baringer, 2003, Small Net heterotrophy in the North Atlantic Ocean diagnosed from organic matter transports.

As we have funding through the NSF for our first year through 9/31/03, other tasks still at hand for this year are

f) To get the data other than those in the initial models described above in (d) to the point where they are ready for inversion. This process includes filling in data gaps, interpolating the bottle data ctd pressures and determining relative geostrophic velocities and the statistics necessary for computing dianeutral transfers. This work is on going.

g) Where crossovers are expected to occur, adjust the data to minimize difference in deep water properties (Johnson et al., 2000). Carbon parameters at crossover points will be available through GLODAP.

We have the GLODAP carbon values, but we have not yet begun handling the cross-over points has this is dependent up step (f) above.

h) To produce objectively mapped, gridded data sets which can be mapped and differenced (where repeat sections exist).

This is happening as we make our way through the data sets.

i) To determine and initial set of boxes for a full Atlantic inversion and to select reasonable initial reference levels for all station pairs.

It will done when step (f) is complete.

2. The reasons for slippage if established objectives were not met.

Although we have not yet completed the first year's work of quality controlling and mapping the input data to the 2db CTD depths, we still hope to be well along with this work by the end of the first year as defined by the NSF side of this proposal which is 9/31/03. As the tech person we are using for this work has not been able to spend as many hours on it as we have funds to pay her, this process is taking somewhat longer than expected. We are attempting to remediate the problem by hiring a second tech person part-time using the NSF first year funds. Also, as stated in part (d) we are ahead of schedule in terms of the model set up.

3. Publications:

Macdonald, A. M., 2003, Oceanic CO2 Transport, Divergence and Air/Sea Exchange in the North Atlantic, CARINA conference, poster.

Also presented at the NSF NACP PI Meeting in May of 2003.

Macdonald A. M., M. O'Neil Baringer, R. Wanninkhof, K. Lee and D. W. R. Wallace, 2003, A 1998--1992 comparison of inorganic carbon and its transport across 24.5 N in the Atlantic, Deep Sea Research II, in press.

Suga T., K. Motoki and A. M. Macdonald, 2003, The North Pacific climatology of winter mixed layer and mode waters, Journal of Geophysical Research}, accepted.

NOAA Progress Report

Ocean Reference Stations

NOAA Grant: NA17RJ1223
July 1, 2002 to June 30, 2003

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The goal of this project is to maintain long-term surface moorings, known as Ocean Reference Stations, as part of the integrated ocean observing system. Under this effort three sites will be established: the site at 20°S, 85°W under the stratus cloud deck off northern Chile (Stratus), the Northwest Tropical Atlantic Station (NTAS), and a site north of Hawaii near the Hawaii Ocean Timeseries (HOT) site. The Stratus and NTAS sites have the background of already having had surface moorings deployed and serviced annually under NOAA OGP support; they will transition to long-term Ocean Reference Stations under this effort. The Hawaii site will be a new Ocean Reference Station site to be done in collaboration with investigators that have made shipboard and moored observations in that region in recent years. In the management of this project four tasks have been identified. First, there is the engineering, oversight, and data management; work in this area is underway and progress reported below. Second, the maintenance of the Stratus site, also with work underway and progress reported below. Third, the maintenance of the NTAS site, which will begin in 2004 when the grant currently supporting for that site ends. Fourth, the establishment of the third Ocean Reference Station, planned for Hawaii; groundwork for this has begun and is reported below.

Task I Engineering, oversight and data: Design of a new buoy for use at the Ocean Reference Stations is nearing completion, and fabrication of the first buoy hull and tower top has begun. These new buoys will replace the 15-20 year old hulls presently used which are degrading (corrosion of the welded aluminum) and are expensive to ship as they do not fit inside a sea container like the new hulls. Construction of the meteorological sensor systems to be used to support the three sites has begun; these will be integrated with the new tower tops and tested. The work under Task I is on schedule.

Task II Stratus Site: The mooring (Figure 1) deployed under the previous grant (under the Pan American Climate Studies) in October 2001 was recovered using the RV Melville (Puerto Caldera, Costa Rica to Arica, Chile) in October 2002 (Figure 2) and a new mooring deployed at the same site. A refurbished buoy hull and fresh ocean and meteorological instrumentation is being shipped to San Diego in September to be loaded on the RV Roger Revelle, the ship to be used to recover and redeploy the mooring in November 2003.

In-situ comparisons of the ship's and both buoys' meteorological sensors are carried out when the mooring is deployed and also when recovered to quantify its in-situ accuracy (Figure 2). During the experiment, hourly-averaged surface meteorology was available in near real time via Service ARGOS and a WHOI ftp site. Data exchanges were made with ECMWF, NCEP and others to examine numerical weather prediction model performance and examine air-sea fluxes under the stratus clouds. The telemetered meteorological data is also available via the website maintained for this site (http://uop.whoi.edu/stratus). Internally recorded 1-minute meteorological data as well as the oceanographic data, which are only internally recorded, were downloaded from the recovered instrumentation. Data recovery was good (estimated to be 90%), post-calibrations are being completed, and preliminary files have been shared with colleagues. A preliminary cruise report was filed with the State Department in December 2002; final documentation was finished in 2003. Telemetry from the buoy presently deployed indicates that it is on station and both meteorological systems are functioning well.

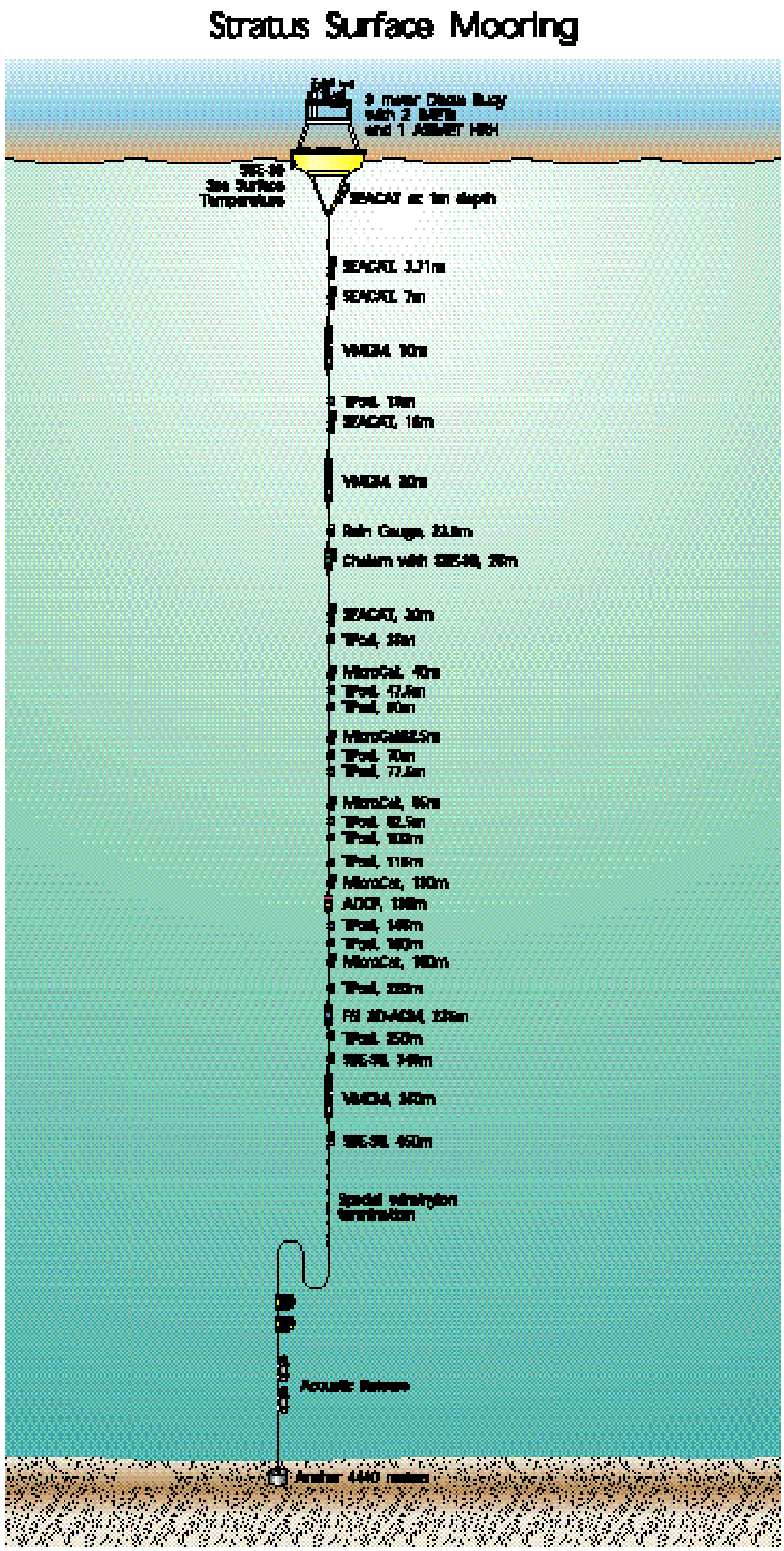
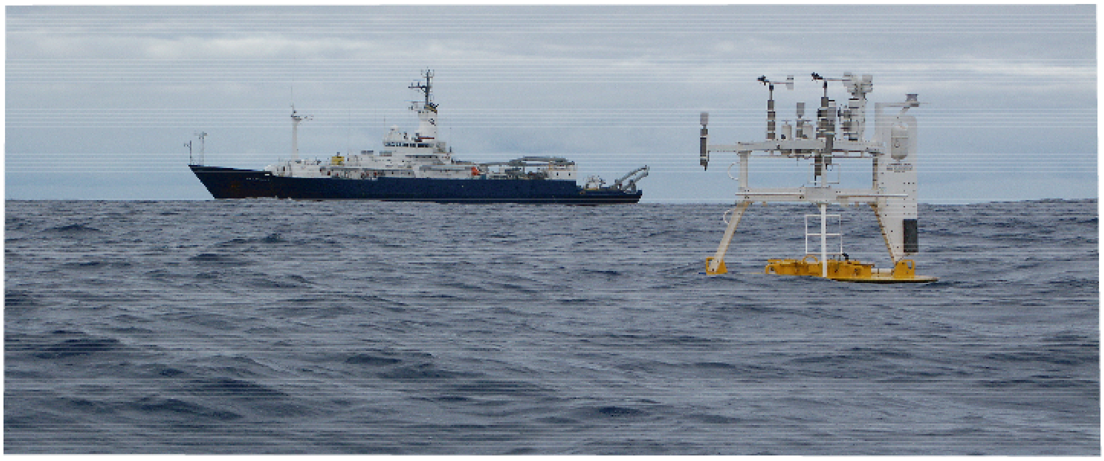


Figure 1 Diagram of the surface mooring deployed at the Stratus Site (20°S, 85°W), showing meteorological and oceanographic instrumentation.

Figure 2. The RV Melville standing by the Stratus mooring during comparisons of shipboard and moored meteorological sensors.



Task III NTAS Site: Work continues on this task under its present grant. Preparations are being made under Task I to prepare for assuming support of the NTAS site at the turn-around cruise to occur in early 2005.

Task IV Hawaii Site: In this first year of this project an effort was made to identify a third Ocean Reference station site that would have high value to the integrated ocean observing system and also that could be maintained without requiring funding beyond that outlined in the present budgets for this project. These criteria would be met if we deployed a surface mooring equipped with two IMET meteorological systems at the HOT site, just north of Hawaii. There are willing collaborators, including Roger Lukas and colleagues at the University of Hawaii, that would participate; and the logistics of cruises in and out of Hawaii are affordable and convenient, as some gear could be left there, reducing cost.

Further, the heritage of prior observations at that site points to the value of an Ocean Reference Station there. During this year we laid the groundwork for this collaboration, and Lukas and colleagues have submitted a proposal to NSF add oceanographic instrumentation to the mooring. This proposal was funded. We are working toward July 2004 as the date for the first deployment and are gearing work under Task I to have the hardware for this site ready to meet that date. The lack of available ship time would be the only factor that would delay work under this task.

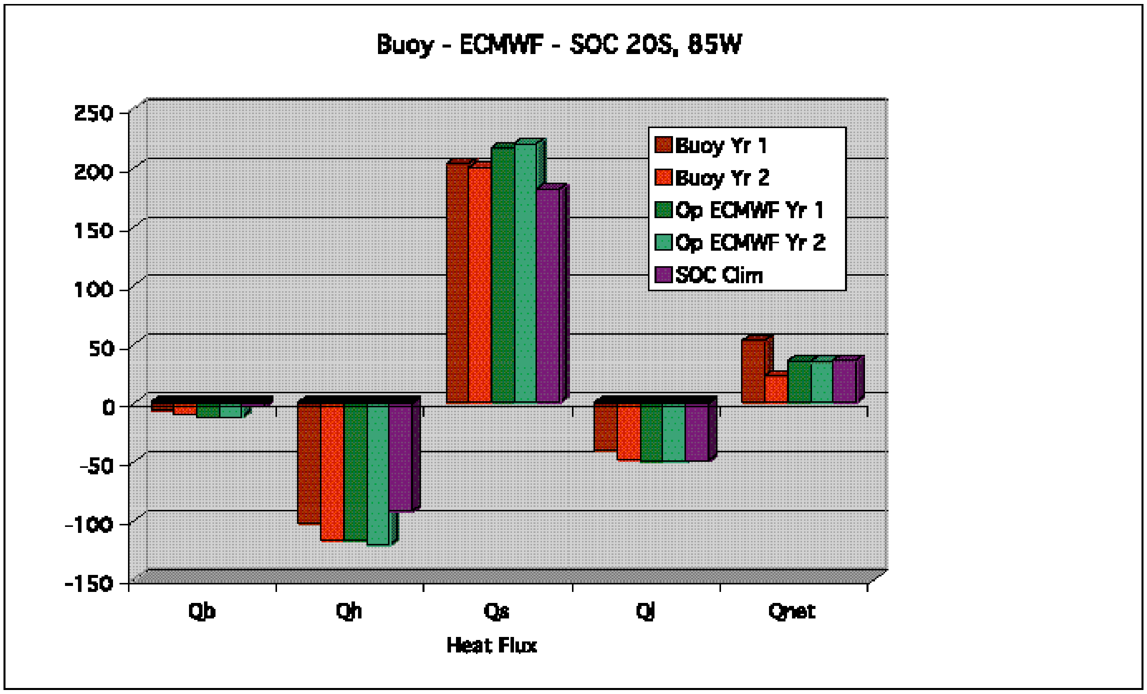


Figure 3. Comparison of the two years of in-situ heat flux from the Stratus buoy with those flux quantities at that site in the NCEP and ECM models. .

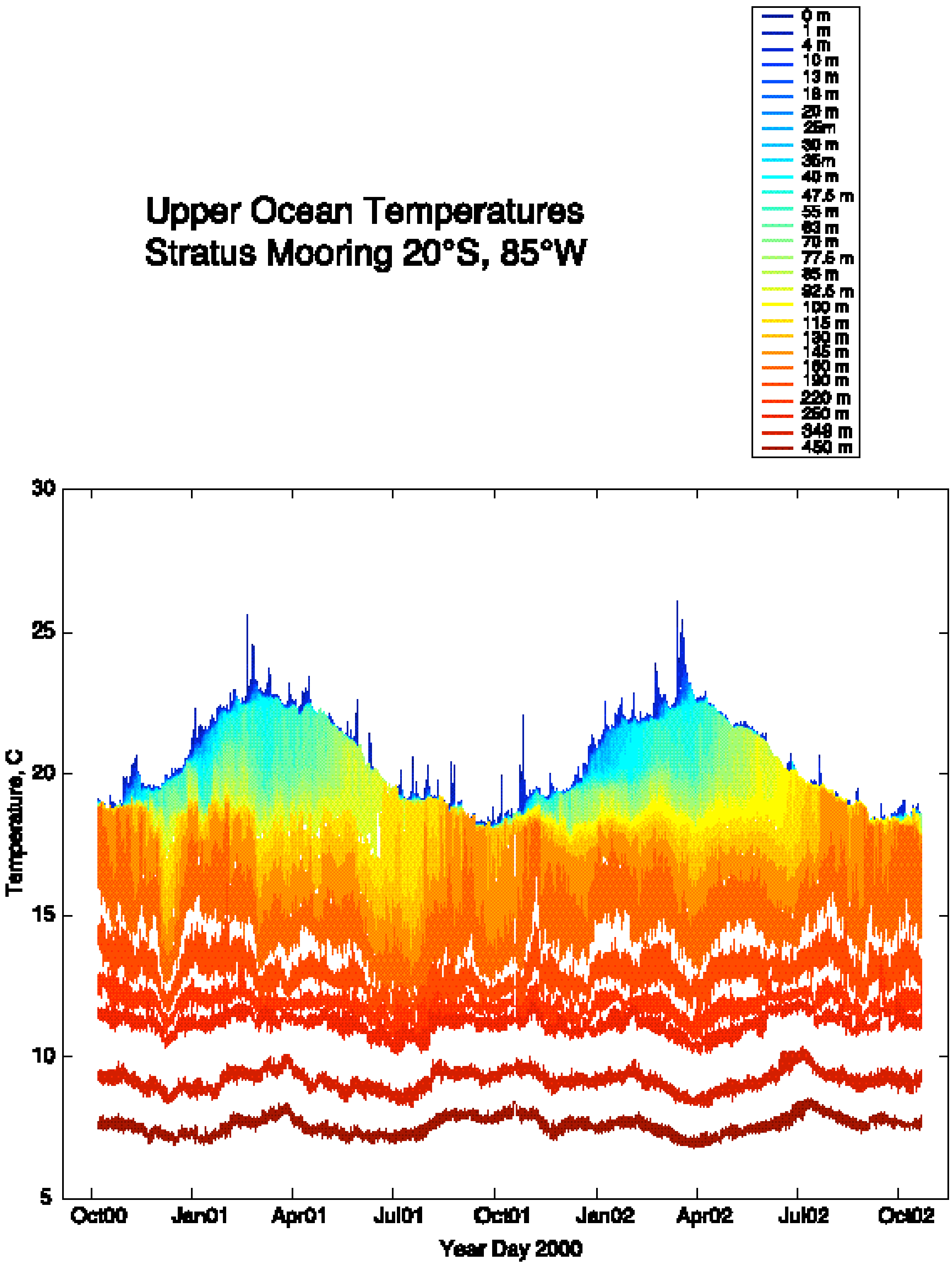


Figure 4. The first two years of upper ocean temperature data at the Stratus Site. This data provides a unique basis for determining the processes that control SST at this site and in turn may play a role in maintaining the stratus cloud deck there.

NOAA Progress Report

The Argo Float Program

NOAA Award No: NA17RJ1223
July 1, 2002 to June 30, 2003

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Objectives

This grant covers WHOI's contribution to phase III of the Argo float program. The activities carried out in the second year of this grant include manufacturing of floats for the Argo array, quality-control of the data, and contributions scientific management of both the Argo Float program and Global Ocean Data Assimilation Experiment (GODAE). An analysis of the data from an array of over 200 floats from the northern North Atlantic was also carried out as a demonstration of the utility of the Argo array.

Status

During the second year of this grant, we have made considerable progress towards getting back on schedule for deploying floats. We have made the transition to manufacturing SOLO floats in house. Early in the year, we continued to have refabricate floats due to problems with leaking bladders and other difficulties. We feel confident that we have overcome these problems and are now on an accelerated production schedule. We are now producing the newer mechanical design of SOLO floats which has made production significantly easier. Sixty five floats were deployed during the last twelve months due to these production problems. We anticipate having this year's allotment of floats in the water or in port waiting for VOS deployment by the end of this calendar year. The floats now use a SEASCAN controller irregardless of the communications system or CTD used by the float. We are now producing between 15 and 20 floats per month.

Approximately one third of the floats use the ORBCOMM communications system. This system has proven to be quite reliable and robust. Using ORBCOMM the floats transmit data with a vertical resolution of 2 dbar in the upper 400 m and 5 dbar at deeper depths. The temperature and conductivity values are reported with a resolution of 0.0005 and the float typically spends less than one hour on the surface. Positions for these floats are obtained using GPS. Unfortunately, there has been some problems getting reliable GPS fixes which we have traced to problems with the ORBCOMM/GPS antennae. We have presently suspended deployment of ORBCOMM floats until we have completed a redesign of the antennae. We expect to resume deploying this flavor of float within the next two months.

For the new SEASCAN controller floats that use SERVICE ARGOS, we have implemented a CRC check into the messages. As a result, we only have to receive an uncorrupted version a given ARGOS message one time which means that we can reduce the time on the surface.   Typical failure rates for ARGOS data communications are 30-40% which means that we can reduce to the time on the surface so that the messages are sent through the system a few times rather than the order time to twenty times that was required in the past.   As a result, we can increase the number of messages required to send the data while still reducing the total number of messages transmitted by the float. We have halved the time that these floats spend on the surface and are now looking at the success rate of the communications.   Indications are that we should be able to reduce this time by at least another factor of two.   This has several benefits. including a reduction of biofouling of the sensors and significant savings in batteries which should lead to longer lived floats. These floats can be equipped with either the SBE or FSI CTDs.

We continue to work with Johnson and Wong to refine the delayed mode quality control formalism for calibrating the conductivity data.   We have found that the North Atlantic is a significantly harder region to carry out this procedure than is the case for the Pacific because of the presence of a larger number of water masses and the much shorter scales of variability along isothermal surfaces.

As part of our quality-control work, we continue to look at data from the new FSI CTD package.   The first float equipped with the FSI package also uses the ORBCOMM satellite system has now completed over 136 profiles on a 5 day cycle.   This float was launched off Bermuda and has basically returned to its launch position after approximately 17 months, and shows little conductivity drift.   This suggests that we now have two viable options for CTDs for the Argo float program.

As part of our effort to demonstrate the utility of the Argo float program, we have completed a manuscript describing the circulation of the Subpolar North Atlantic Ocean using profiling floats (Lavender, Owens, and Davis, 2003).   This manuscript has been accepted for publication in Deep-Sea Research.   This analysis used the float displacements at depth to deduce the large scale circulation in the region.   The circulation included strong boundary currents along the northern rim of the basins with significant cyclonic recirculation just offshore.   Strong topographic steering was also present.

References

Lavender, K. L., W. B. Owens, and R. E. Davis, 2003. The Mid-depth Circulation of the Subpolar North Atlantic Ocean as Measured by Subsurface Floats, Deep-Sea Research, (accepted).

NOAA Progress Report

GLOBEC Target Species

NOAA Grant: NA17RJ1223
July 1, 2002 to June 30, 2003

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The goal of GLOBEC is to understand and predict how marine species respond to global climate change. Among the uncertainties in a warmer global climate is the extent to which upwelling will increase or decrease in specific boundary current systems, such as the California Current System, and consequently affect the productivity and community structure and function. Our interdisciplinary research, as part of the U.S. GLOBEC Northeast Pacific program, analyzes top trophic level predators (i.e., marine mammals and seabirds) in the northern California Current System (CCS) relative to mid-trophic levels and bio-physical coupling in the system. Among our objectives is to develop predictive bio-physical models of mammal and seabird occurrence patterns in order to improve our understanding of the mechanisms involved in ecosystem change, thus to improve predictability and management of living marine resources important to coastal communities.

Analyses of the coupled bio-physical data sets for two process cruises in the northern CCS during spring and summer 2000 have been completed and submitted for publication (Tynan et al., 2003; Ainley et al., 2003). We have examined the correspondence between cross-shelf and along-shelf variation in physical forcing, oceanographic features, productivity, prey fields (as represented by acoustic backscatter at 4 frequencies), and cetacean and seabird occurrence patterns. Occurrence patterns of cetaceans and densities of seabirds were compared with 13 – 19 hydrographic and ecological variables (e.g., sea surface temperature, sea surface salinity, thermocline depth, halocline depth, chlorophyll maximum, depth of chlorophyll maximum, distance to alongshore front, and acoustic backscatter at 38, 120, 200 and 420 kHz) derived from instruments on a towed undulating array (SeaSoar) and a four-frequency acoustic system. The percentage of variation in occurrence patterns explained by our logistic regression models (up to 84%) for four species of cetacean (humpback whale, Pacific white-sided dolphin, Dall's porpoise, and harbor porpoise) are among the highest ever achieved, and are likely a result of the concurrent acquisition of fine-scale oceanographic data with the cetacean survey data (Tynan et al., 2003). Multiple regression models for 12 species of seabirds explained up to 62.5% of the variance in distributions (Ainley et al., 2003). Our analyses of cetacean and seabird distributions in the northern CCS show the importance of the along-shore front, vertically integrated backscatter at specific frequencies (i.e., prey), and the chlorophyll maximum to resolve top trophic distributions. Processes important to top trophic levels include flow-topography interactions between the upwelling front and jet with bottom topography at a submarine bank and at a large coastal promontory on the eastern boundary current circulation. The responses of cetaceans and seabirds to biophysical processes in the northern California Current upwelling system are both seasonally and spatially specific.

Publications:

Tynan, C.T., Ainley, D.G., Barth, J.A., Cowles, T.J., Pierce, S., and Spear, L.B. 2003. Cetacean distributions relative to ocean processes in the northern California Current System. Deep-Sea Research II (Submitted).

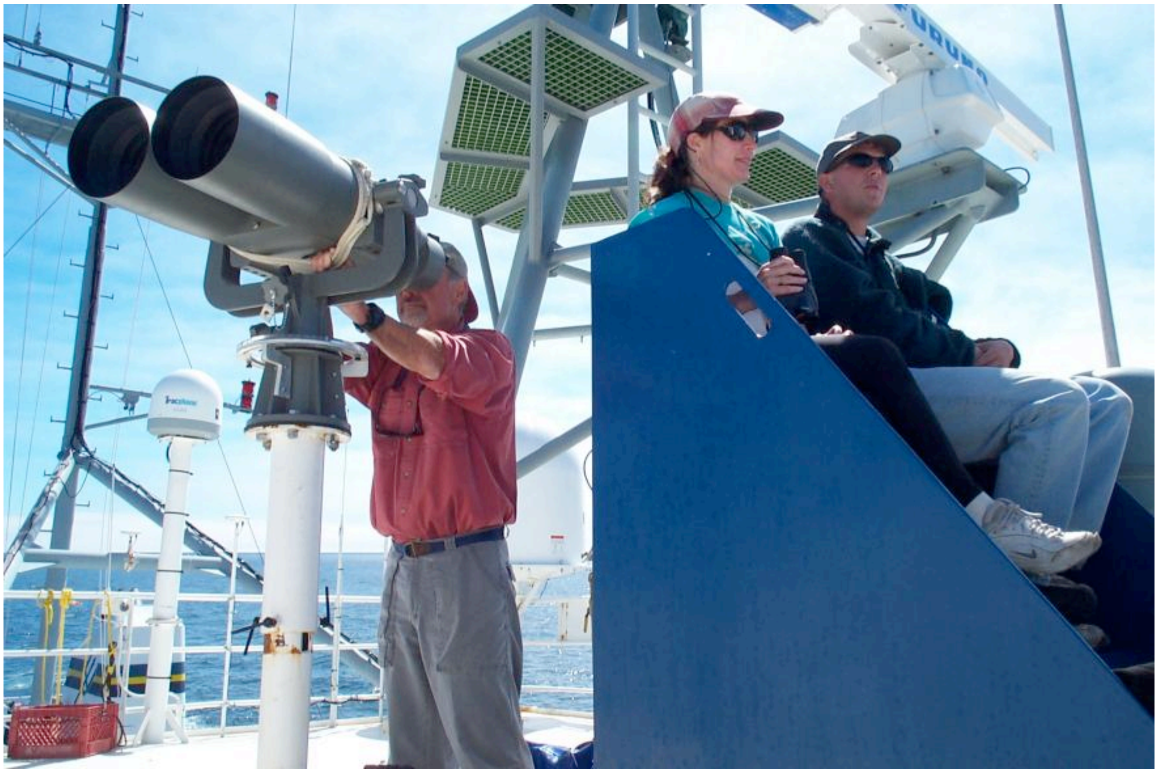
Ainley, D.G., Spear, L.B., Tynan, C.T., Barth, J.A., Cowles, T.J., and Pierce, S.D. 2003. Factors affecting occurrence patterns of seabirds in the northern California Current, spring and summer 2000. Deep-Sea Research II (Submitted).

Batchelder, H.P., Barth, J.A., Kosro, P.M., Strub, P.T., Brodeur, R.D., Peterson, W.T., Tynan, C.T., Ohman, M.D., Botsford, L.W., Powell, T.M., Schwing, F.B., Ainley, D.G., Mackas, D.L., Hickey, B.M., Ramp, S.R. 2002. The GLOBEC Northeast Pacific California Current System program. Oceanography 15: 36-47.

Professional talks:

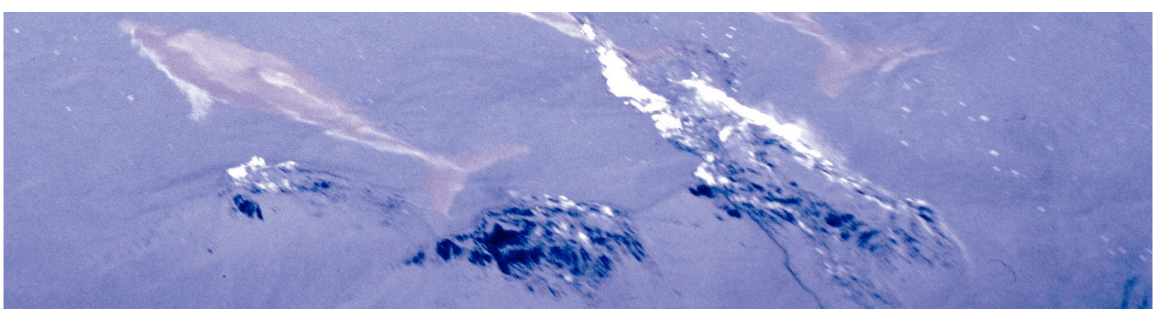
Tynan, C.T., Ainley, D.G., Spear, L.B., Barth, J.A., Cowles, T.J., Pierce, S.D., Peterson, W.T., Brodeur, R., Batchelder, H., Strub, T., Thomas, A., 2002. Mesoscale distributions of cetaceans and seabirds: 2000 and 2002. GLOBEC PI Meeting, Corvallis OR, November 2002.

Tynan, C.T., Ainley, D.G., Spear, L.B., Barth, J.A., Cowles, T.J., Pierce, S.D., Peterson, W.T., Brodeur, R., Batchelder, H., Strub, T., Thomas, A., 2003. Mesoscale distributions of cetaceans and seabirds relative to oceanographic processes in the northern California Current: A GLOBEC study, 2000 and 2002. ONR/IFO- London, January 21, 2003.



Line-transect surveys of cetaceans in the northern California Current System during a GLOBEC Northeast Pacific process cruise. M. Newcomer, C. Tynan and T. Pusser (from collection of C. Tynan).

Pacific white-sided dolphins (*Lagenorhynchus obliquidens*) in the northern California Current System, June 2000. Photo by C. Tynan.



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	JI Lead Author		NOAA Lead Author	
	FY01	FY02	FY01	Fy02
Peer-reviewed	26	40	0	0
Non peer-reviewed	0	23	0	0